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Climate-Neutral Districts: Outlook for Industrial Parks

A Guidebook

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Climate-Neutral Districts: Outlook for Industrial Parks

A Guidebook

Project report as of Wednesday, 1 June 2022

ABC	*Agent-Based Control*
AGEB	*AG Energiebilanzen e.V.*
BCR	*Building Coverage Ratio*
BDEW	*Bundesverband der Energie-und Wasserwirtschaft e.V.*
BMWi	*German Federal Ministry for Economic Affairs and Energy*
CAPEX	*Capital Expenditures*
CBI	*Climate Bonds Initiative*
CECEP	*China Energy Conservation and Environmental Protection Group*
CHP	*Combined Heat and Power*
COP	*Coefficient of Performance*
CSRD	*Corporate Sustainability Reporting Directive*
CTS	*Commercial, Trade and Services Sector*
Dena	*German Energy Agency*
DNSH	*Do No Significant Harm*
DGNB	*German Sustainable Building Council*
DIN	*Deutsches Institut für Normung (German Institute for Standardisation)*
DSM	*Demand-Side Management*
EEN	*Energy Efficiency Networks*
ESCO	*Energy Service Company*
ESG	*Environmental, Social and Governance*
ETES	*Electro-Thermal Energy Storage*
EU	*European Union*
FAR	*Floor Area Ratio*
FSI	*Floor Space Index*
GBP	*Green Bond Principles*
GFA	*Gross Floor Area*
GHG	*Greenhouse Gases*
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit*
ICMA	*International Capital Market Association*
ICT	*Information and Communications Technology*
ILO	*International Labour Organisation*
IPSF	*International Platform for Sustainable Finance*
KPI	*Key Performance Indicator*
LBBW	*Landesbank Baden-Württemberg*
LCA	*Life Cycle Assessment*
LowEX	*Low Exergy*
MPC	*Model Predictive Control*
NDRC	*National Development and Reform Commission of the PRC*
NFRD	*Non-Financial Reporting Directive*
NGFS	*The Network of Central Banks and Supervisors for Greening the Financial System*
NPV	*Net Present Value*
OECD	*Organisation for Economic Co-operation and Development*
OPEX	*Operating expenses*
P2G	*Power-to-Gas*
P2H	*Power-to-Heat*
PBC	*People's Bank of China*
PLC	*Peak Load Contribution*
PV	*Photovoltaic*
SDGs	*Sustainable Development Goals*
TEASER	*Tool for Energy Analysis and Simulation for Efficient Retrofit*
TEG	*Technical Expert Group on Sustainable Finance*

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Preface

National governments have recently refined the objective of avoiding all human carbon emissions. Germany plans to achieve climate neutrality by 2045, and China aims to reach zero carbon emissions by 2060. These years represent important milestones in the fight against climate change. Climate targets are further defined and translated by federal, regional and local authorities. At the moment, there is momentum for legislative changes on every regulatory level. The need to avoid stranded assets and, on the contrary, even become a frontrunner in this new setting is a clear target for district management and local authorities. Therefore, increased competitiveness and more business opportunities are the main drivers for achieving climate neutrality at this level of action.

In addition to individual strategies to achieve this goal, private and public companies, as well as citizens, need to work together to create new emission-free ecosystems in cities. The integrated district approach comes into play here as the district is the most effective level at which the problem can be tackled and climate neutrality achieved. As the largest manageable unit, districts create synergies between several end users and individual stakeholders, bundling local potential. These synergies can be used to couple the energy and end-use sectors. Combined mixed-use of infrastructures can significantly reduce costs and lead to new business models. Further synergies on the energy side can take the form of intelligently linking heat storage systems and electric vehicle charging stations. Optimised electricity and heat charging can maximise the use of (locally) available renewable energies.

This guidebook outlines a step-by-step approach for local authorities and decision makers implementing climate-neutral districts. The aim is to provide practical advice and the necessary background information for district development on the path to climate neutrality. The listing of key indicators provides implementors with the necessary tools to plan and quantify projects of this kind. In terms of the implementation process, there are crucial differences to standard developments from the very start. Recognising these differences and acting accordingly is ultimately decisive for the success of these projects. This guidebook also compares the latest scientific concepts with business strategies that exist in the market, integrating descriptions of best practice examples.

This guidebook is a product of the Sino-German Demonstration Project on Energy Efficiency in Industry initiated by the German Federal Ministry for Economic Affairs and Energy (BMWi) and the National Development and Reform Commission of the PRC (NRDC) and jointly implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, the German Energy Agency (dena), and the China Energy Conservation and Environmental Protection Group (CECEP). The content is derived from a workshop process that took place in 2021 and where various aspects of district energy development were discussed among a group of twenty or so German companies active in the sector. The consulting firm heatbeat provided theoretical foundations for technical aspects. The Frankfurt School of Finance provided input on the topic of green finance. This guidebook is the product of the technical input, lively discussions and conclusions drawn by dena.

Pathways to climate-neutral districts

Why should we be on the pathway?

The potential for energy savings, emissions and reducing energy costs at the district level is considered an important component of the transformation to climate neutrality. There are many more side benefits beyond the described benefits of the integrated district approach, such as quality of stay. Various synergies exist between the different sectors in the district, such as energy sectors (heat, cold, electricity, mobility) and end-use sectors (housing, commercial/ trade/services (CTS), industry, transport). Compared to an approach at the individual building level, the district can unlock economies of scale with pooled infrastructure use, planning and purchasing. Reducing costs, which increases competitiveness and profits, is a major factor for the integrated district approach. It can also be applied in different settings and serve as a blueprint for district development in various regions and settings. Climate-neutral districts make an important contribution to the energy transition at the local level because they maximise the use of local climate neutrality potential (renewable energies and waste heat) and contribute to the more efficient use of land. They enable new business models as a platform for different products and services. However, their operation depends heavily on the regulatory frameworks for energy, buildings, city planning and many more.

What does this mean?

In the context of this guidebook and the preceding workshop series, climate-neutral districts are defined as districts that do not emit any greenhouse gases (GHG). The climate neutrality objective is considered to be achieved if the energy demand is completely covered by renewable energies or waste heat and the local climate neutrality potential is maximised. Therefore, climate neutrality represents the overarching goal and is measured in GHG emissions. In dense urban areas, climate neutrality is difficult to achieve in the district itself, so integrated interaction with nearby regional resources and higher-level infrastructures is always required. Due to the uncertainty of the transformation outside the scope of local players, general plans to transform central infrastructures are needed from the respective infrastructure operators. These can be followed and tracked with mid- to long-term perspectives and checked against national climate targets.

The practical implementation of climate neutrality at the district level is still in its infancy. There is no standardised methodology or precisely applicable parameters for the conceptual design and later planning. In practice, this means that the implementing districts must first find define a project-specific balance boundary and interim objectives as well as develop long-term transformation strategies. Therefore, this guidebook is relevant for all district developers, even if substantially reduced emissions rather than climate neutrality is the objective.

The necessary individual steps and phases are summarised in the next section entitled ‘How can it be done’ as a guide for district developers.

How can it be done?

Step 1

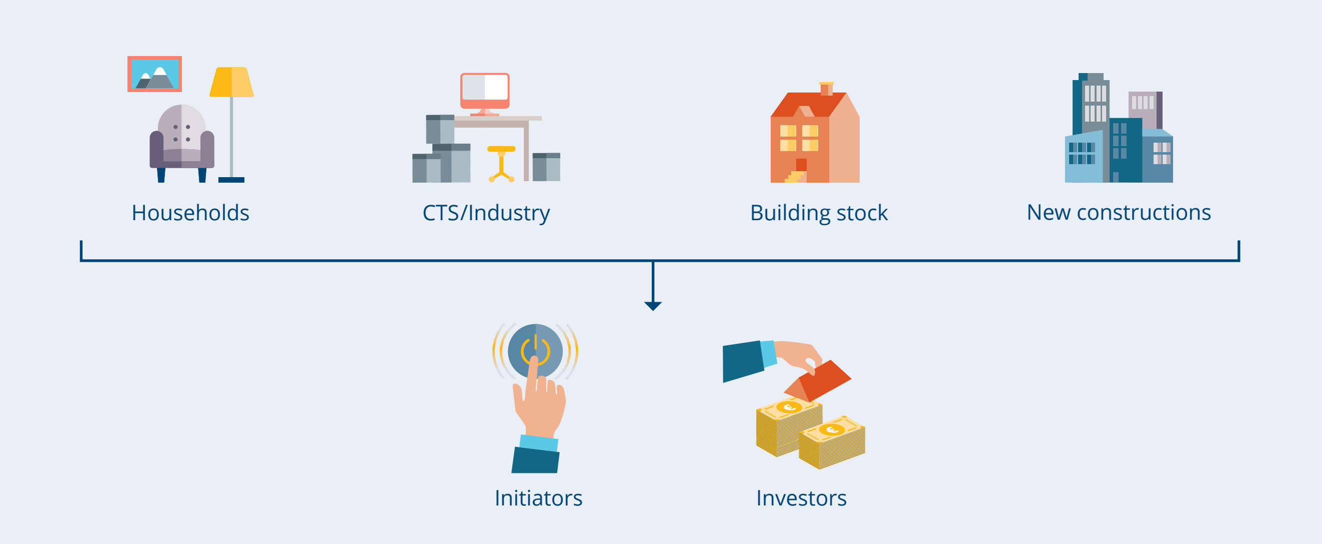
Project initiation and key stakeholders

Climate-neutral districts need to involve a wide range of professional stakeholders and adopt new cooperation formats based on integrated planning, design and management approaches across all sectors and disciplines. Climate-neutral district planning is inherently interdisciplinary as it involves the cross-cutting issue of energy. It mostly evolves from the demand side, represented by buildings and large industries, if present.

The drive for development comes from the resolution for climate neutrality and thus the definition of the objective of climate neutrality, to which all newly added stakeholders must also be committed. Initiators and investors form the core team of each individual district development project. Both these roles can also be fulfilled by a single company or institution, depending on the size and ownership structure of the project. The more roles a single stakeholder fulfils, the less communication effort is required. For developers, this often translates into the search for an anchor customer or an anchor generator. If an investor is also the system's end user, the potential to achieve climate neutrality is increased. If the district is not the remit of a single stakeholder, as is often the case in practice, there must be a motivation phase. This motivation phase generates the necessary commitment and interest among the various stakeholders needed, for instance, to unlock investments for common infrastructures such as heat grids. Once the overall climate-neutral district concept has been elaborated, it is possible to attract or address the missing stakeholders. It is often useful to include these stakeholders as early as possible and ensure their commitment to continue participating.

Following the drive for development, it is crucial for the implementation of climate-neutral districts that, in addition to the core team, the subsequent stakeholders become involved: planners, developers, operators and end users. It is recommended that a coordinator act as an advocate for climate neutrality to communicate and mediate between the stakeholders and ensure the achievement of the climate neutrality target. Here, the stakeholders' expertise, needs and requirements need to be brought together. Forward-looking participation planning can substantially increase the overall support among stakeholders.

Sectors and stakeholders relevant for project initiation



Step 2
Definition of climate-neutral district boundaries

The term district or energy district is not clearly defined in the literature. There are different ways to define multiple buildings or part of a city as a neighbourhood. Possible categories are municipal or political boundaries, the existence of certain infrastructures (e.g. traffic routes or medical complexes) or the social environment. A district is often defined based on the size of the area under consideration and the usage structure of the buildings within the district. Energy balance limits are also used to define energy districts. Consequently, a distinction needs to be made between the energy sector and the end-use sector groups. The definition is strongly dependent on the stakeholders involved since only those sectors can be influenced for which active transformation or development decisions can be made.

Furthermore, decisions have to be made with regard to the spatial boundary. They can be defined by political, architectural, natural or traffic boundaries, making their implementation very flexible. Sometimes nearby infrastructures or areas can be included, such as wind parks or large industries with waste heat potential. The municipality, which is responsible for urban land use planning as well as urban mobility infrastructures, is key in defining the spatial layout.

Additionally, life cycle considerations must be made. Within the project scope, it has to be decided whether the energy requirements are taken into account only for the operational phase or for the entire life cycle of the district's buildings, infrastructures, and facilities. With buildings and equipment becoming more and more energy efficient, the amount of energy embodied in the materials (grey energy) becomes an important criterion. This often considers the production phase and is therefore also referred to as 'cradle-to-gate'. If all the life cycle phases are considered, it is referred to as 'cradle-to-grave'. The terms 'circular economy' or 'cradle-to-cradle' are used when the products are added to a new life cycle. A simplified overview of the different life cycle steps is shown in the figure below.

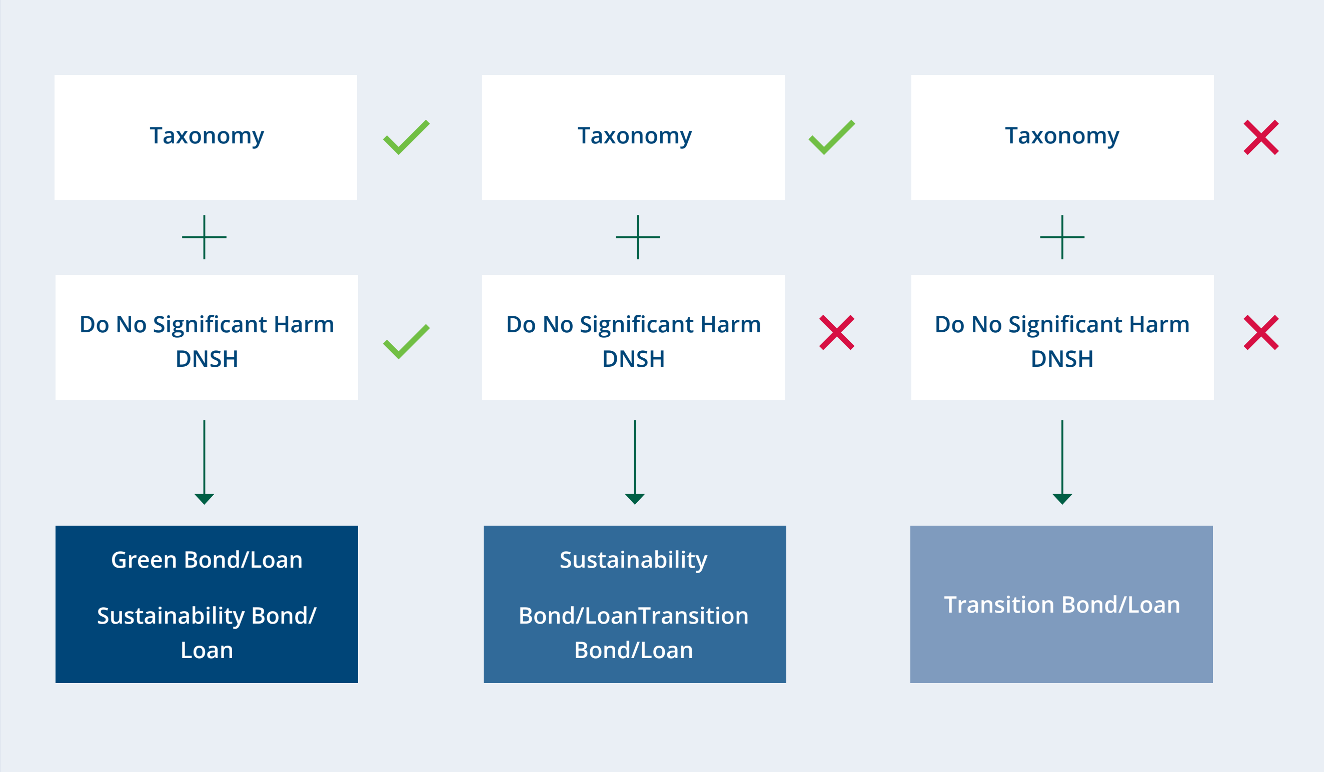
Overview of the life cycle

Step 3

Green and sustainable financing

Green finance can be considered a useful approach for financing district projects and defining relevant key performance indicators (KPIs) for achieving climate neutrality. The instruments it encompasses, such as green bonds or green loans, are increasingly attractive as their interest rates are ultimately lower. Moreover, financial institutions and companies are subject to continually increasing disclosure and reporting regulations, and the disclosure of climate risks and climate mitigation activities has become an important market reputation criterion. Before matching suitable financing options (such as green bonds, green loans or sustainability-driven direct investments) to the energy system to be configured, it is important to consider the corresponding financial frameworks, such as the EU taxonomy, in advance. A simplified decision tree for the choice of relevant financial instruments is given below.

Decision tree for the choice of financing instruments

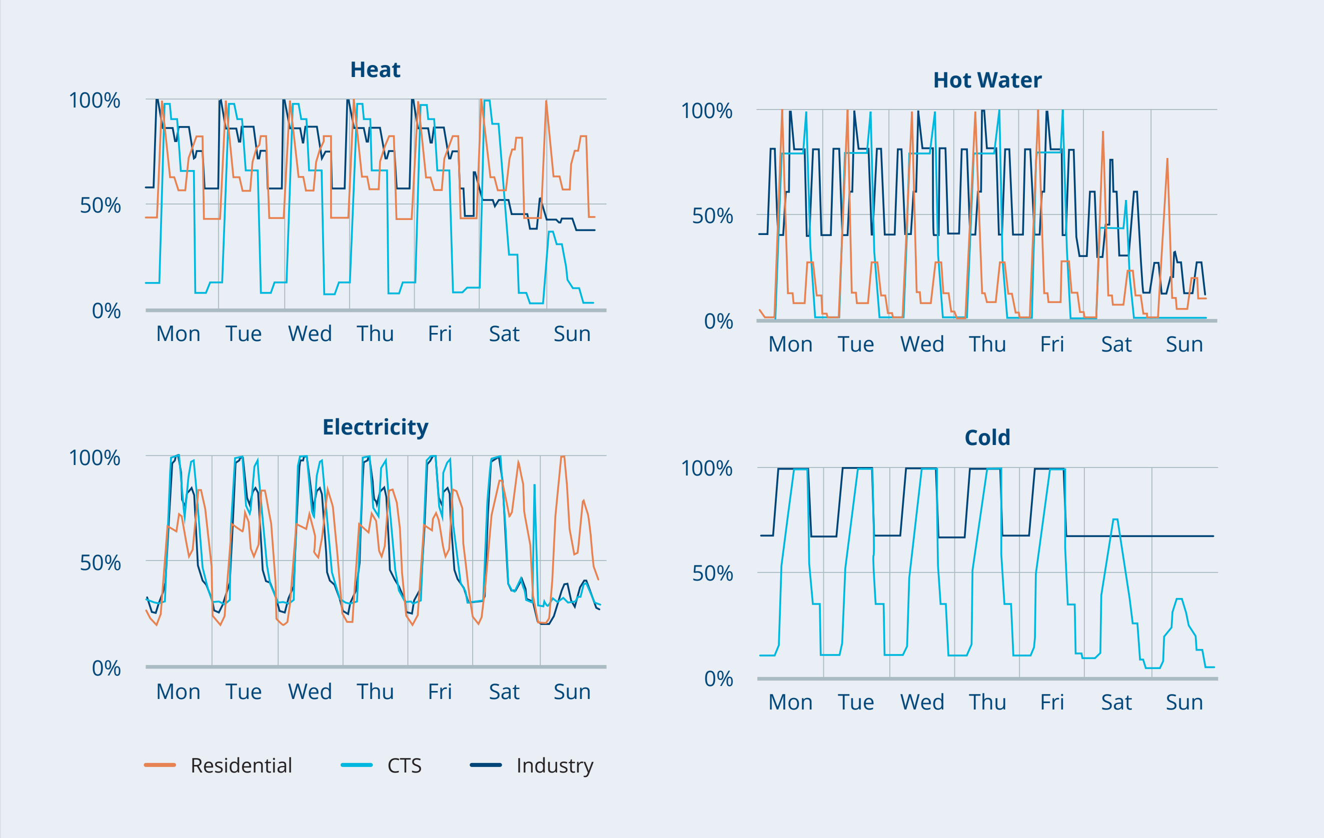


Step 4
Energy concept I: Characterisation of the energy demand

Before analysing the overall energy demand patterns, the core team must consider implementing specific building policies to create a uniform standard for all buildings within the district. Investors who might later join the project must then also adhere to this standard. Moreover, energy transition management for company processes should be introduced early on to continuously promote goals and achieve change.

As for the concrete characterisation of the district's energy demand, the time resolution of different types of energy demands (electricity, heat, cooling and mobility) must be generated based on a time series (for example, in 15-minute increments). Potential local synergies need to be identified as early as this step. The aim is to shift demand between energy and end-use sectors in the form of sector coupling as well as the specific load profile via demand-side management. It is very common to also work with demand scenarios in this step. From this step onwards, digital planning tools (such as simulations or digital twins) must be integrated as normalised load profiles do not reflect the complexity and potential of synergies.

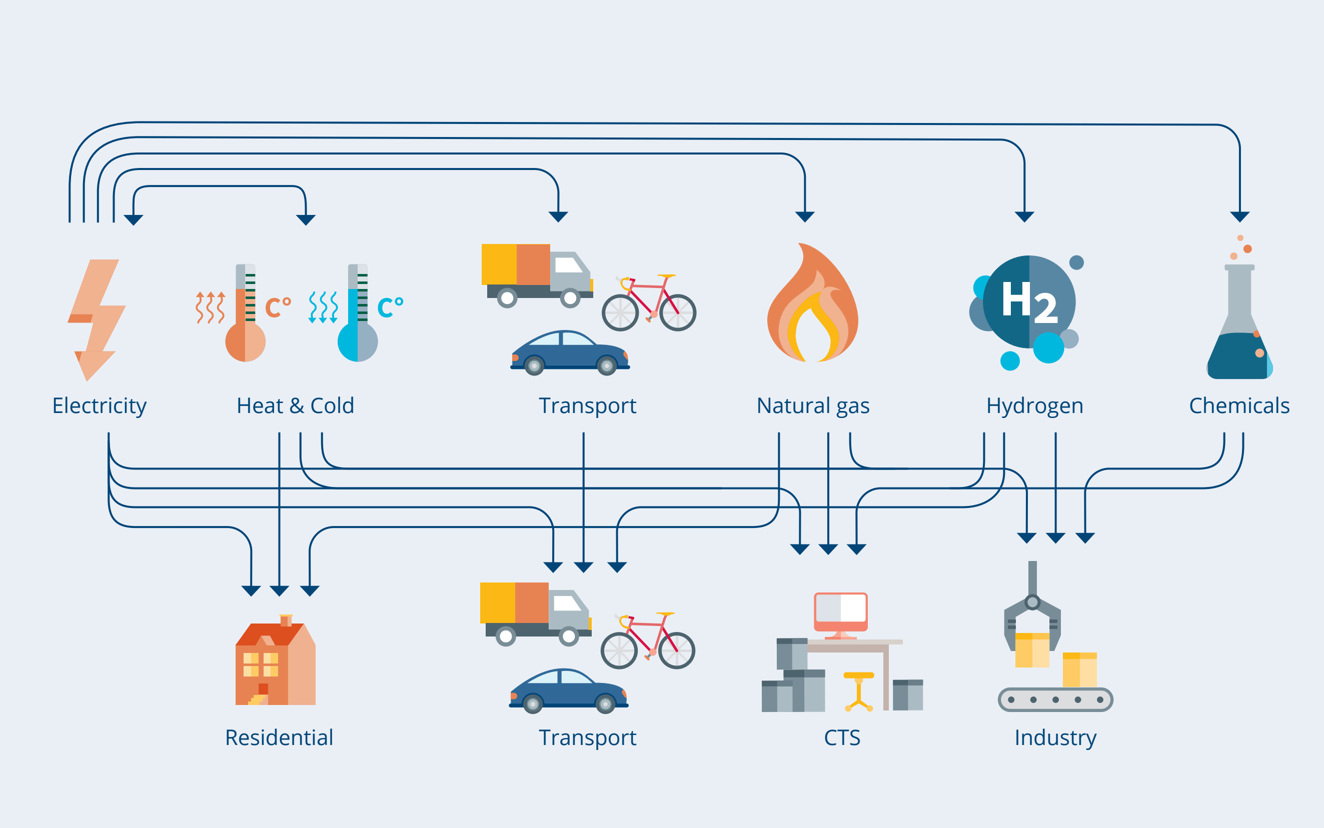
Load curves in an exemplified district for a week across different end-use sectors



Step 5
Energy concept II: Characterisation of the energy potentials

Following the characterisation of districts and their corresponding energy demand, their energy supply is the next relevant consideration. In this step, the useful climate neutrality potential is identified and evaluated. In addition to potential in the immediate vicinity of the districts, the wider outlying region must also be considered to characterise the possible energy supply options. Different energy supply scenarios can be derived depending on the availability of information on the aforementioned energy potential. Basic information on local potential could include available roof surfaces and open areas as well as solar radiation that can be used to generate solar energy. Other important potentials include regional wind, biomass or geothermal potential and, most notably, waste heat potential, such as from nearby industrial processes.

Interconnections between energy sectors and end-use sectors

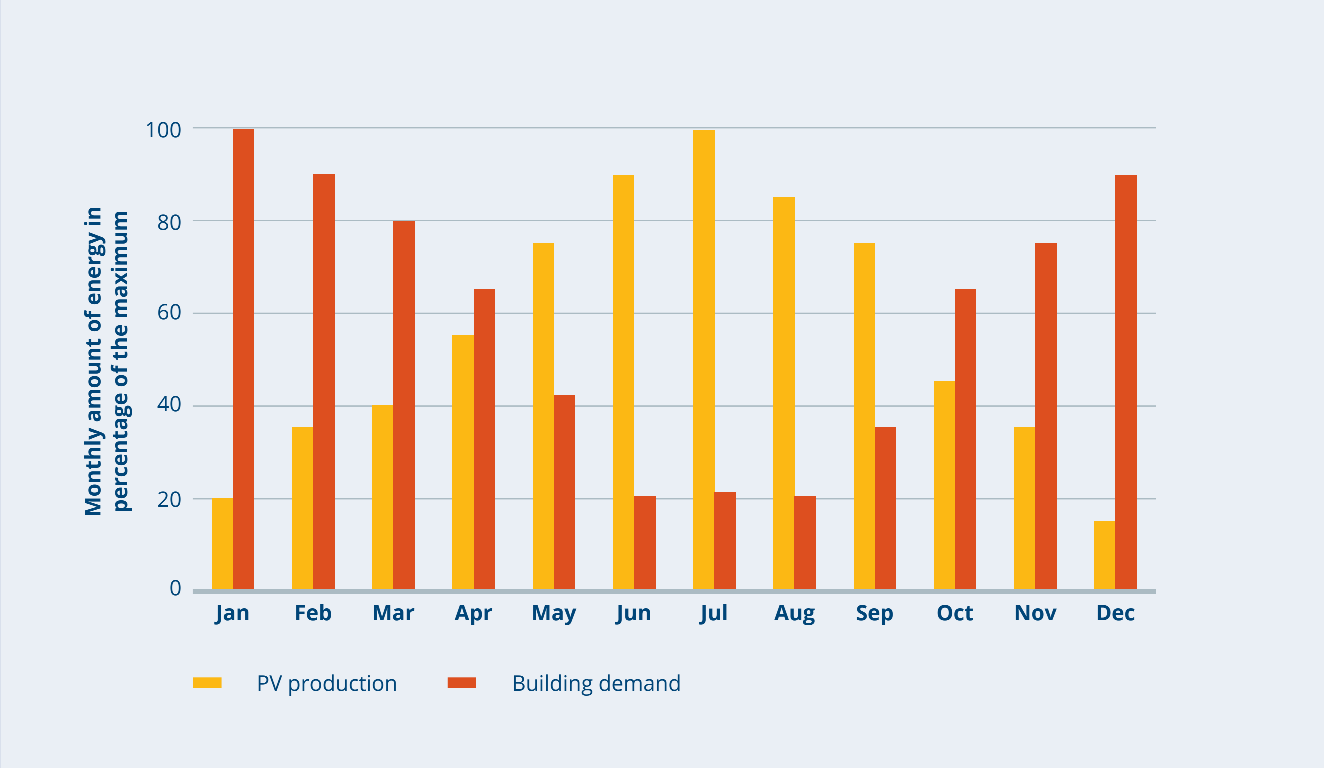


Step 6
Energy concept III: Technical configurations and scenario planning

The energy system configuration is designed in this step. The chosen technologies for electricity, heating and cooling generation and distribution depend on the energy demand (step 4) and the available climate neutrality potential (step 5). For climate-neutral districts, sector coupling technologies are often used to account for demand-side management and load shifting effects on overall system efficiency. Moreover, storage capacities, such as batteries and thermal storage, maximise local renewable energy use. The latter even enables sector coupling, e.g. by providing thermal energy to industrial processes.

Until now, it was hardly possible to achieve climate neutrality in the short term as local decentralised energy systems also depend mostly on central infrastructures and the availability of climate-neutral energy carriers and the economic feasibility of applying the relevant technology. Therefore, long-term transition plans on the centralised level are needed for local-level planning. Additionally, scenario planning must include external change and disruptions (regulatory, socio-economic, environmental and technological).

PV production compared to building demand in relation to the maximum for that year

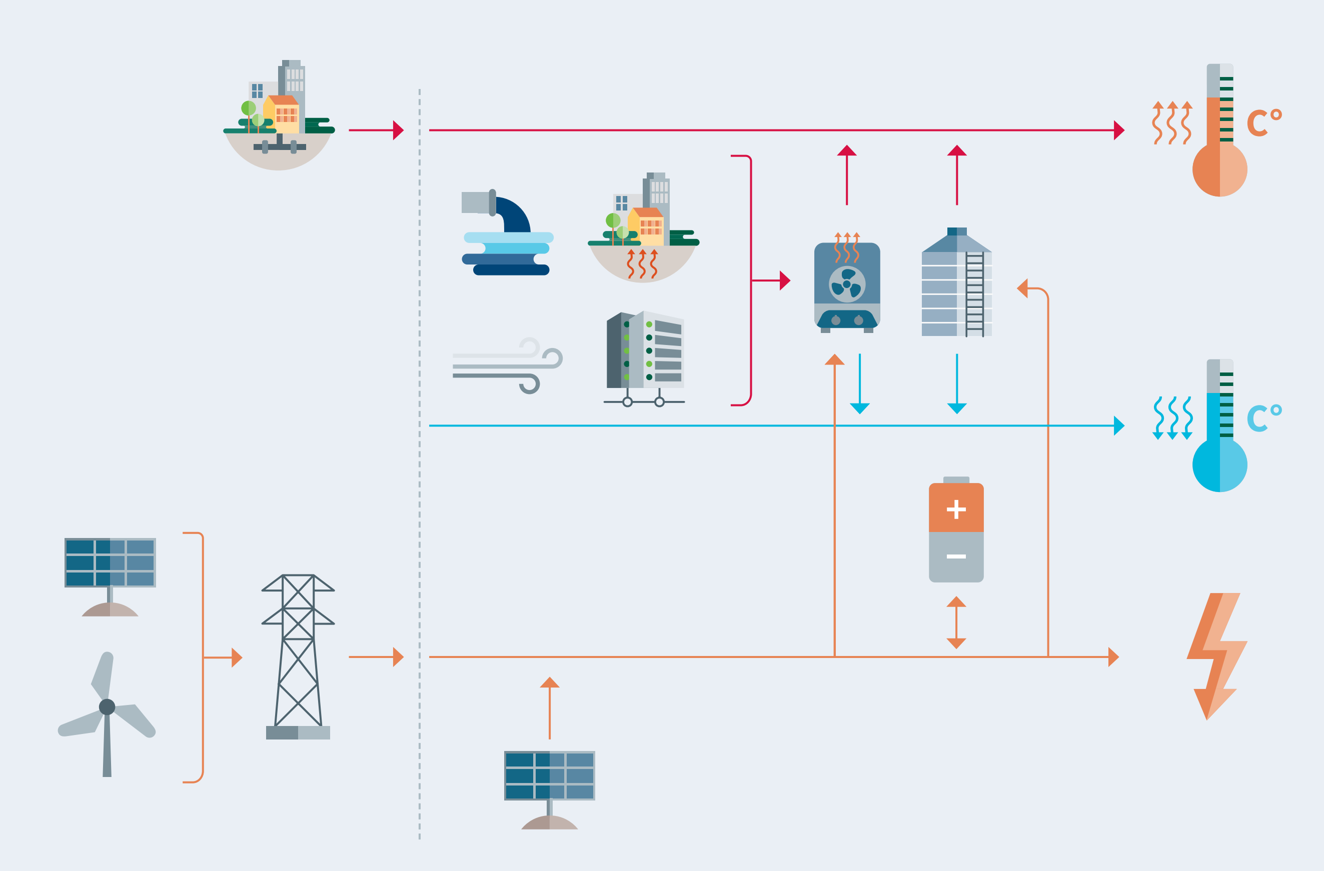


Step 7
Detailed planning and implementation phase

In this step, the developed concept is further detailed and finally implemented. Normally, this phase takes several years. The planning and, ultimately, also the implementation often take place separately at the infrastructure and building level. In this phase, a lively exchange between the planning team at the infrastructure level and those at the building level is important. Such an exchange requires experienced planners who pursue an integrated approach and a strongly interlocked planning of the trades and stakeholders. For the life cycle assessment (LCA), it is necessary to include long-term planning with possible changes in use and the ultimate reuse of building materials after deconstruction.

A high level of qualified consulting services is still needed for the actual detailed design of climate-neutral districts and their implementation. Moreover, forward-looking quality control helps to achieve the anticipated project performance goals as the quality of the planned and implemented project is directly related to energy performance. Expertise can be derived from relevant company networks, such as Energy Efficiency Networks (EEN).

Energy system configuration for a district's energy system in the all-electric scenario



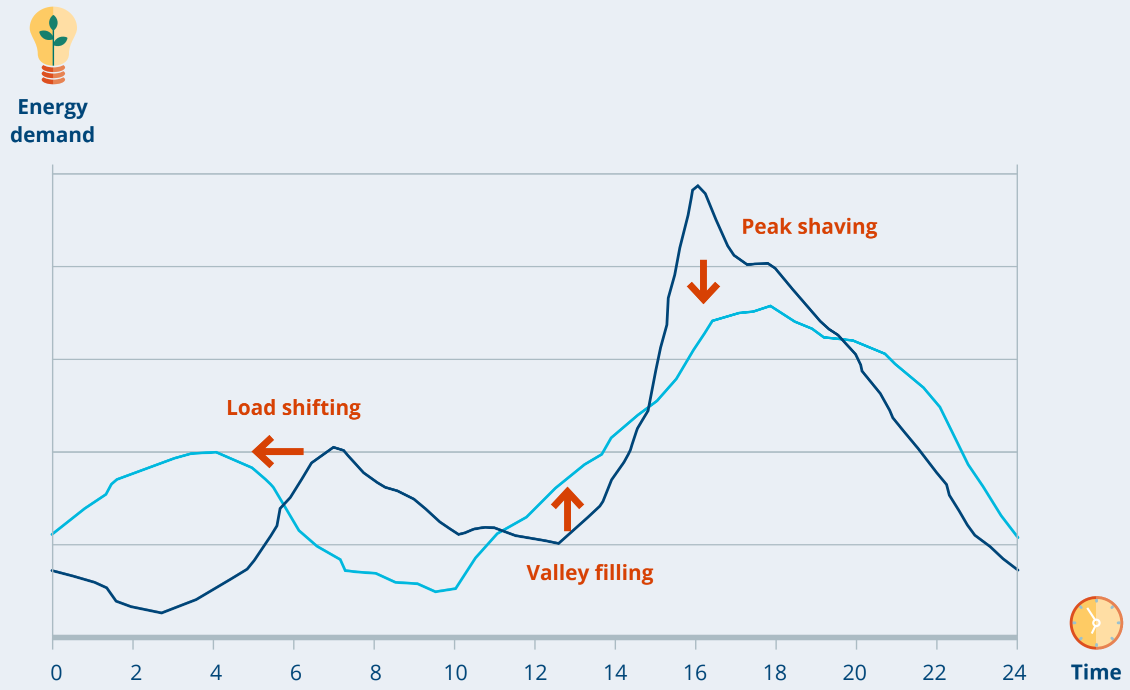
Step 8
Operation phase

The operation phase is the longest of the described phases. During this phase, climate-neutral districts must demonstrate high system efficiency on paper or in simulations as well as in practical operation. Moreover, inefficient device settings should be identified to avoid unnecessarily high operating costs. Monitoring and subsequent optimisation are key to verifying and possibly readjusting the energy system configuration as it was designed in previous steps.

Control systems based on real-time monitoring form an important part of the climate-neutral operation of district energy systems. Here, sector coupling can be adjusted on a real-time basis to minimise costs and GHG emissions based on the actual climate-neutral energy potential. The optimal use of infrastructures, such as grids, storage and energy supply and demand, can be achieved by (automatically) reacting to the signals of the control system. Different demand-side management strategies, such as load shifting, valley filling and peak shaving, can be applied here.

After the district and its facilities have been operated successfully, an after-use concept of the infrastructures, devices or materials needs to be developed. Modularity can help to avoid lock-ins in specific technologies and uses. Also, the expensive disposal of waste can be avoided. The recyclability of materials and thus also the deconstruction of buildings is sure to become even more important in the future in the context of the discussion on resource scarcity. However, this industry is still in its infancy.

Demand-side management strategies shown on a load curve



Step 1:
Project initiation and key stakeholders

Although the stakeholders are always distinct in every district, the vital roles are relatively similar across different district types. Based on the position and role of the stakeholders in the process and their influence on development decisions, they can be divided into two categories: key roles that play a decisive role in determining the project design (Section 1.1) and numerous secondary stakeholders that indirectly influence the district development on the implementation level (Section 1.2). Figure 1 provides an overview of these roles.

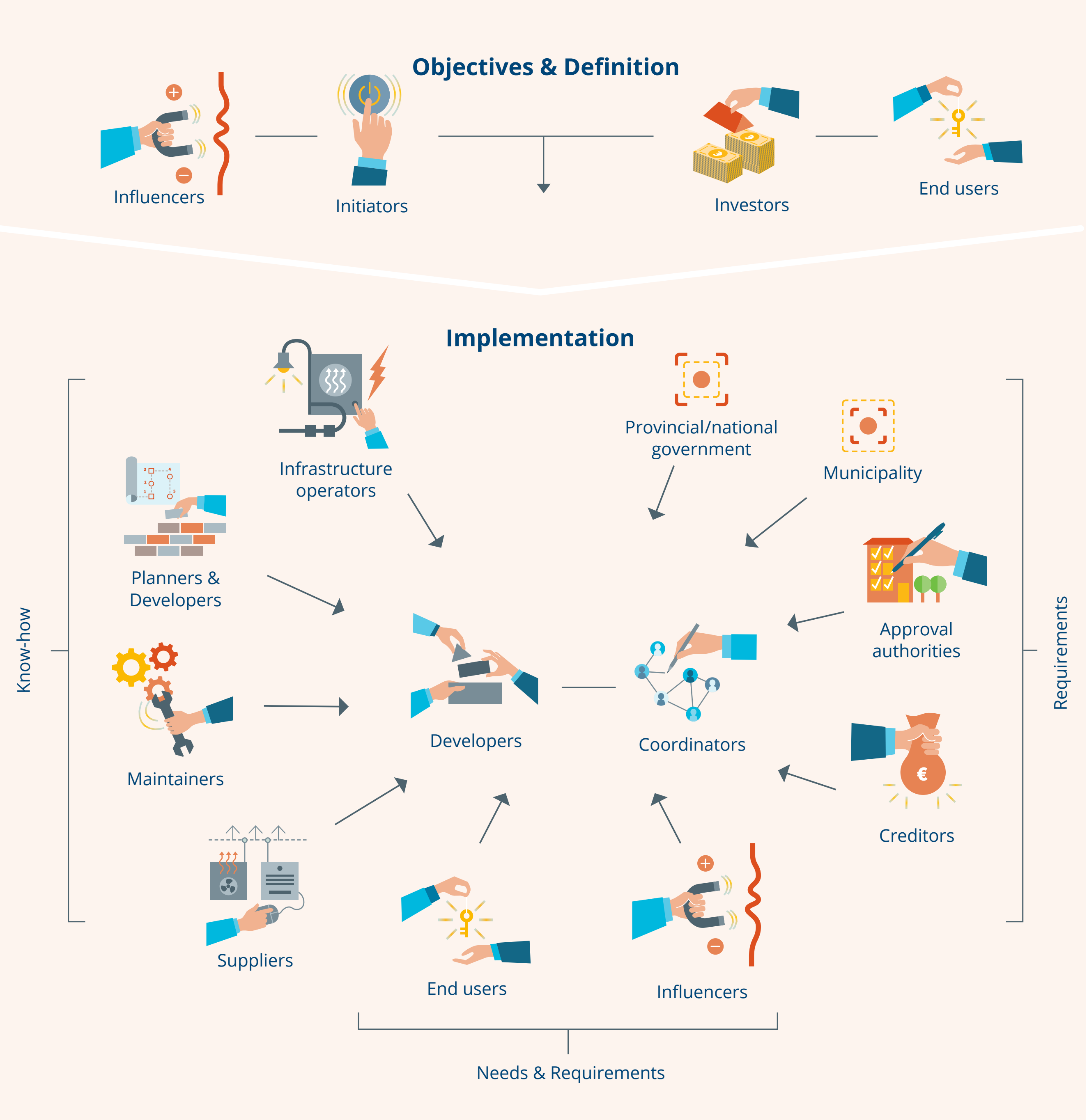


Figure 1: Stakeholder map for the definition of objectives and subsequent implementation

1.1 Decision-making level

The two key roles on the initial decision-making level consist of the initiator and the investor. The initiator defines the objectives in the respective district, including the climate neutrality objective. The investors raise the necessary funds for the district's development. Ideally, these two roles are fulfiled by a single stakeholder. The more roles a single stakeholder fulfils, the less communication effort is required, which increases intra-process efficiency. However, these roles can also be fulfilled by a consortium, e.g. of multiple investors.

The key stakeholders mostly evolve from the energy demand side as buildings and industries with large energy demands. This role can also be fulfiled by an energy service company (ESCO) or a large industry with waste heat potential looking for potential customers. For developers, this often translates into the search for an anchor customer or anchor generator, i.e. a single stakeholder with significant economic and energetic capacities. If an investor is also the system's end user, the potential to achieve climate neutrality is increased.

Once this core team is established, it is necessary to activate the other stakeholders to achieve the following:

- Higher motivation by participation
- Integration of relevant expertise and concepts
- Higher quality by involving more perspectives, expertise and relevant aspects

The initial decision-making level also includes influencers such as neighbours or local associations in addition to the end users. A major difference exists between existing and newly developed districts. At the beginning of construction projects, the end users are often unknown, so their demands are shaped more indirectly, e.g. by the real estate market.

If the district is not the remit of a single stakeholder, as is most often the case in practice, the following implementation phase must be flanked by motivation campaigns to include other necessary stakeholders.

1.2 Implementation level

At the implementation level, several other roles need to be fulfiled by qualified stakeholders. There are three main groups: expertise holders (infrastructure operators, planners, developers and technology suppliers), stakeholders demanding requirements (local authorities, approving authorities, financers) and influencing groups (end users, local associations).

Initiation of district development

A key to successful stakeholder management is the constant and long-term commitment of an initiator in the district. Sometimes an institution with communication, moderation and mediation expertise can continue the long-term district development and pursue the implementation of a concept if the initiator does not have the resources and capacity. Motivation and commitment over many years are necessary to ensure continuity, a level of action among stakeholders, and to act as a contact institution for all key stakeholders.

In the case of heterogeneous investor groups, such as private companies and individual house/apartment owners, an inclusive PR-flanked strategy is necessary to keep motivation and commitment high over the entire project period. The work of motivation and persuasion can often be arduous, especially in heterogeneous neighbourhoods. Therefore, it can be useful to begin by implementing individual, less complex project components that serve as demonstrators and calls for people to join the change movement. For this spirit to emerge, these sub-projects must result in visible benefits to convince the groups. Such benefits might be, for instance, the greening of formerly depreciated areas or the upgrading of a lighthouse building that exemplifies the benefits of climate-neutral operations. Compared to the establishment of a heat grid, for instance, such measures are visible and create the necessary momentum for private action in the district.

It is recommended that a coordinator advocate for climate neutrality and moderate between the stakeholders if there is not yet an interface between them. In the event of conflicting objectives, this coordinator could also act as a mediator to ensure the district achieves the objectives it set. Forward-looking participation planning can substantially increase the overall support among stakeholders.

Takeaway:

When developing a climate-neutral district, initiators should be aware of the necessary stakeholder constellation, the different roles and their specific contribution to the overall objective of climate neutrality. There are two levels within the development process: The decision level and the implementation level. All the involved stakeholders must declare their willingness to contribute to climate neutrality and work constructively towards that objective throughout the entire development process.

Step 2: Definition of climate-neutral district boundaries

The term district or energy district is not clearly defined in the literature. There are different ways to define multiple buildings or part of a city as a neighbourhood. Possible categories are municipal or political boundaries, the existence of certain infrastructures (e.g. traffic routes or medical complexes) or the social environment. A district is often defined based on the size of the area under consideration and the usage structure of the buildings within the district. Energy balance limits are also used to define energy districts.

A more detailed explanation, with particular emphasis on the aspects crucial for defining an energy district or an integral energy concept, can be found later in this chapter. In this guidebook, the term 'energy district' is understood to mean a localised area of several buildings where the buildings and other district components use synergies mutually. With that in mind, this chapter will first address the definition of the size and balance boundaries of energy districts (Section 2.1). Then, the characterisation of the energy demand will be described (Section 2.2). The final point related to the definition of a district's boundaries, the topic of local energy conversion and conversion chains, will then be highlighted (Section 2.3).

2.1 Definition of size and balance limits in energy districts

As stated above, there is no uniform definition of the size of energy districts. That makes it all the more important to characterise buildings and areas as possible components of a district at an early stage using relevant key figures and to start deriving suitable metrics based on these key figures. The building and population density are particularly decisive for further energy planning and conceptual design. Important parameters and their definition for the characterisation of districts based on existing or planned areas can be found in Table 1 and Table 2. The definition of structural densities is partly derived from German industry standards (DIN) but can also be applied as physical quantities to international building stocks.

The variables make it possible to draw direct conclusions for the future energy system, particularly the structural density. For example, the floor area ratio (FAR) can be used to determine how much of the roof surfaces are theoretically available for energy applications (regardless of any superstructures such as lifts and orientation). To better classify structural density, some district types are provided along with their typical structural density values in Table 3. The classifications and definitions by Dettmar, Drebes and Sieber (2020) serve as an illustration here and do not constitute a general definition. Depending on their primary use of these examples, the various designs make it clear that the structural shape and the use of the districts have a decisive influence on a district's energy system. This is discussed in more detail below.

Importance of early involvement of stakeholders

Examples of districts on paths towards climate neutrality already exist. Industry and municipal energy utilities are the main drivers for such projects. All of them share the characteristic of stakeholder groups being integrated at an early project stage and the consequent development of feasibility studies upfront. Learnings from these studies and pilot projects are crucial to maximise renewable energy usage by means of storage technologies and to create synergies.

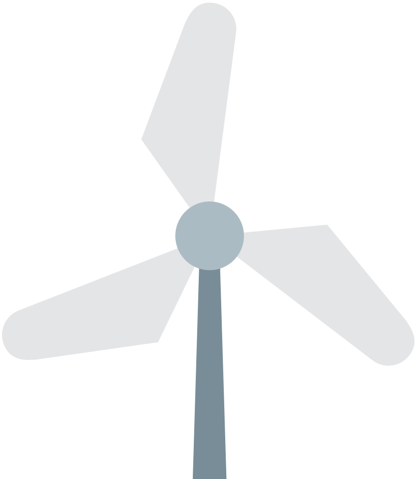
Existing projects and customers in the district mostly see CO_2 neutrality rather than climate neutrality as the objective. However, as climate neutrality is strictly related to all types of GHG emissions and includes carbon sinks, this political ambition should be considered when planning a CO_2-neutral district. Moreover, in the finance sector, all GHG emissions are considered as calculated in CO_2 equivalents.

Type	KPI	Unit
District area	Open spaces	[ha]
	Traffic areas	[ha]
	Construction area	[ha]
Census	Number of buildings	[ ]
	Population	[ ]
	Employees	[ ]
Structural density	Gross Floor Area (GFA)	$[m^2]$
	Floor Area Ratio (FAR)	[ ]
	Building Coverage Ratio (BCR)	[ ]
	Volume	$[m^3]$

Table 1: KPIs of a district's balance limits

Structural density	
Gross Floor Area (GFA)	According to DIN 277-1:2005-02 and DIN 277-2:2005-02, the gross floor area is the sum of the total area of all floors of a building. It is calculated by multiplying the floor area by the number of floors. The gross floor area is an absolute size.
Floor Area Ratio (FAR)	The floor area ratio, sometimes called floor space index (FSI), is the ratio between the gross floor area (GFA) and the land area of a building. It describes the actual structural density by taking all floors into account.
Building Coverage Ratio (BCR)	The building coverage ratio is the ratio between the building area and the land area, making it a simplified structural density metric.
Volume	To determine the gross room volume according to DIN 277-1, the gross floor area is multiplied by the ceiling height. The gross room volume is an absolute size.

Table 2: Structural density explanations



The key figures presented enable the characterisation of several buildings or an entire district. However, they do not clearly classify the size (e.g. area or number of buildings) that can properly define a district. Therefore, a district must normally be spatially demarcated according to the local context of the individual case.

However, this spatial demarcation is not usually sufficient for the consideration of energy systems. Instead, a balance limit for the energy and material flows of the energy district must be derived from it in a further step. Definitions and terms from specialist literature on energy systems at the city level can be used and transferred from the city level to the district level.

Research on the topic of urban energy systems is particularly helpful for this purpose. According to Keirstead (2012), a definition in this context first provides a general definition for an energy system from Jaccard (2006). He defines an energy system as "the combined processes of acquiring and using energy in a given society or economy".

This quote makes it clear that an energy system, even with a self-sufficient supply, is never limited to a building, a district or an entire city. The process chains required for production and use extend far beyond a city's borders (e.g. production of Photovoltaics (PV) modules in Asia). Jaccard (2006) also shows that markets, institutions and consumer behaviour affect the planning and operation of an energy system ("given society or economy").

One option is a purely geographical approach ("Pure Geographic") that only takes into account all technologies within an administrative boundary. The "Geographic Plus" concept also includes energy flows, which can be tracked with a reasonable effort (for example, importing electricity from other balance limits). Keirstead (2012) offers a third option called "Pure Consumption", which refers to people's actions rather than the spatial demarcation. This approach takes into account all the activities of a city's inhabitants; the location does not matter. For instance, energy consumption at a holiday resort would be assigned to the energy balance of the holiday goer's hometown.

The theoretical considerations of Jaccard and Keirstead show that processes also influence the assessment of the energy balance outside a district (Jaccard, 2006; Keirstead, 2012). To quantify this influence, a life cycle assessment (LCA) can be applied. An LCA describes a quantitative method for assessing different environmental impacts from human activities and is standardised according to DIN EN ISO 14040. Many different parameters are available to assess environmental impact in three categories:

- Energy demand (energy, primary energy, export energy, etc.)
- Global warming potential (CO_2 emissions, global warming potential in CO_2 equivalent)
- Other environmental impacts (e.g. freshwater resource needs, acidification potential)

DIN 15804 specifies the life cycle analysis for construction products, after which a total of four life cycle phases of the buildings or necessary products are distinguished.

Residential district with single-family houses and small multi-family houses, usually 1 to 3 stories and with up to 260 m^2 of living space.	BCR	0.12 – 0.17
	FAR	0.19 – 0.42
Residential districts with large, 7- to 16-room apartment buildings arranged irregularly and extensively.	BCR	0.13 – 0..17
	FAR	1.77 – 2.31
An inner-city district characterised by mixed-use and high building density. The exact use and characterisation vary considerably depending on the city.	BCR	0.52 – 0.81
	FAR	1.17 – 2.05
Commercial districts are characterised by single-storey buildings with connected or detached 2- or 3-storey office and administration buildings.	BCR	0.25 – 0.5
	FAR	0.4 – 0.6

Table 3: Average values for characteristic districts

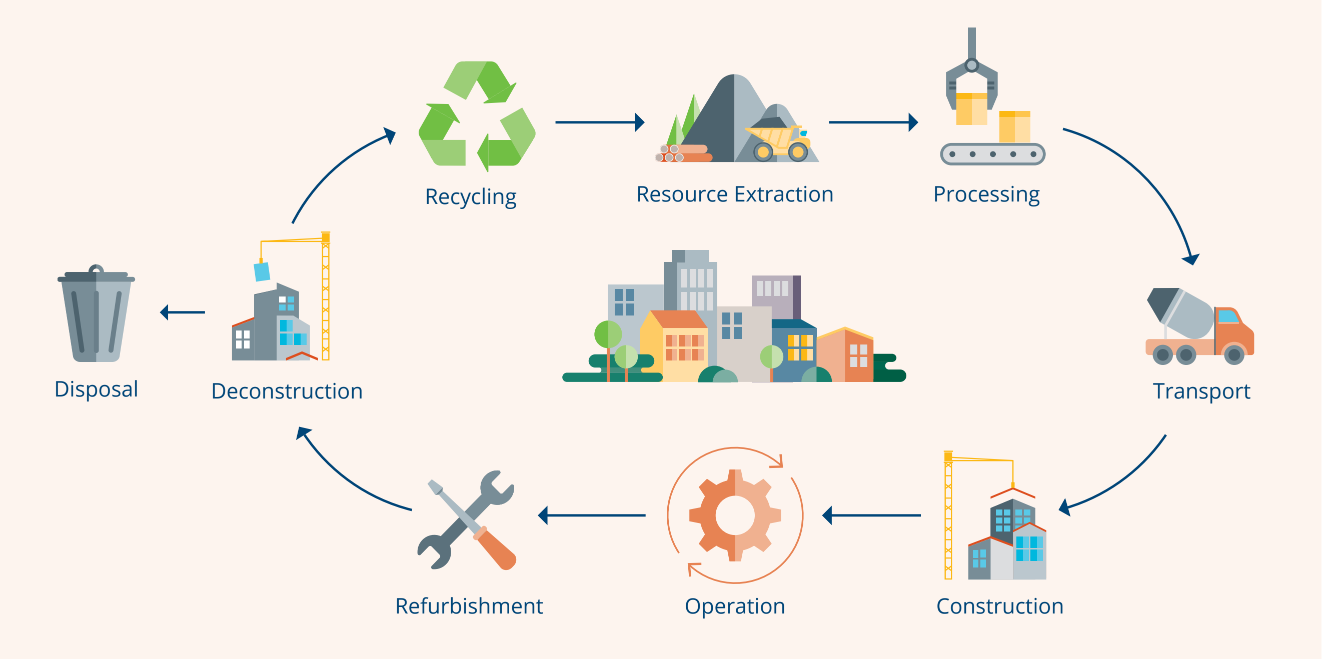


Figure 2: Overview of the life cycle

1. Manufacturing phase: This includes all processes that can be assigned to the raw materials or their extraction, processing to the final product and transport to the construction site. For example, cement production includes the use of energy for the extraction and further processing of raw materials such as limestone or clay, as well as the thermal treatment of the raw materials up to the finished product.
2. Construction phase: The construction phase comprises all processes that are directly or indirectly related to the construction. An example is the further processing of cement into concrete (e.g. energy demand from concrete mixers).
3. Use phase: All the processes to ensure the operation of the building are defined at the outset of the use phase, namely the supply of electrical and thermal energy. Any refurbishments are also part of the use phase, which in turn are linked to building materials.
4. Disposal phase: The end of the life cycle encompasses all the processes used in demolition, disposal or recycling.

With the addition of transport and renovation between the steps, the LCA is summarised in Figure 2.

The definition of different life cycle phases makes it possible to define balance boundaries. Often, only the use phase is considered. For construction products, the energy bound in the building material is often referred to as ‘grey energy’. This often considers the production phase and is therefore also referred to as ‘cradle-to-gate’. If all the life cycle phases are considered, it is referred to as ‘cradle-to-grave’. The terms ‘circular economy’ or ‘cradle-to-cradle’ are used when the products are added to a new life cycle.

The application of a life cycle analysis to evaluate districts and district energy systems holds promise. Unfortunately, the LCA only provides guidance through the different project stages and with the components used, but no further specification on the balance limits of either a building or a district. Districts have complex component supply chains, making traceability and transparency a major challenge.

Showcase: Super Circular Estate in Kerkrade, Netherlands

The Dutch government aims for a fully circular economy by 2050, with an interim goal of a 50% reduction in raw material consumption by 2030. While a large proportion of construction and demolition waste is already downcycled into materials for roads, for instance, new buildings are hardly ever made from recycled products. Therefore, significant innovations are required in the construction industry to achieve circularity. One such innovative project is the Kerkrade Super Circular Estate in the Parkstad Limburg region.

In the next 30 years, the population of the Parkstad Limburg region is expected to shrink by 27% due to population ageing and young people moving to urban agglomerations. Therefore, the high-rise apartment buildings built in the 1960s to address the housing shortage are becoming superfluous, especially since they no longer correspond to current living comfort requirements. The Kerkrade Super Circular Estate project used the materials from one such 10-storey high-

rise to build single-family pilot housing units with different recycling techniques to prove their viability and replicability.

The process for building with recycled materials is not standard, with one of the major differences being the interactions between the parties. For instance, the construction and deconstruction companies need to be involved from the very beginning as the architects need to design a new building based on what materials are available, which means less planning freedom.

The project showed that building new housing units with up to 95% reused materials is possible, although a certain percentage of new materials is necessary. The following circular techniques were tested during the construction of the three pilot buildings:

- *Circular concrete foundations (7% new cement)*
- *Main loadbearing structure of the two houses has been directly reused from the existing building by cutting 3D concrete modules from the existing structure*
- *Main loadbearing structure of the third house has been made of circular concrete (aggregate and cement for the concrete, 5% new cement for the structural walls)*
- *Partitioning walls and door frames have been directly reused*
- *Façade has been constructed out of brick cut-off elements, recycled concrete and parts using crushed concrete pieces from the deconstructed building*

Regardless of the level of technical decomposition and recovery, all reuse and recycling strategies tested during the project had better performance regarding CO_2 emissions, embodied energy and material savings than conventional construction methods. For example, the recovery of a tunnel-shaped 3D concrete module saved 34% of CO_2, 34% of embodied energy and 95% of raw materials compared to conventional construction with concrete.

A material passport for each building is an important instrument to show the characteristics of the materials used to help future planners reconfigure the building materials. The Dutch government recently introduced tax incentives for developers who register material passports for their buildings and is considering making it a mandatory requirement for all new projects in line with its ambition to achieve a circular economy by 2050.

Life cycle assessment in district development

The lack of a comparison of the various stages is the main barrier to a wider application of life cycle assessments (LCA). Definitions and clear metrics, which a regulatory framework should provide, are lacking. As the life cycle of products is mainly addressed in the planning & implementation phases, this phase requires clear signals regarding, e.g. emissions and implications from upstream phases as well as the recycling, second life and disposal of the materials.

Resource extraction & processing: Increased transparency and availability of data on grey energy is necessary here.

Construction: Definitions and standards for climate-neutral construction are needed to avoid redefining ‘climate-neutral construction’ for each individual project.

Operation: Here, GHG emissions are already measured well and must be reported for taxation and other purposes. A possible additional step would be to incorporate a higher time resolution for emissions resulting from operation. This can take needs from central infrastructures as well as security of supply more into consideration.

Renovation: Up to now, the focus on the operation phase has disadvantaged renovation and the subsequent reduced use of materials and, therefore, grey energy.

Recycling & Disposal: Modularity can ensure the use of a material or product in another context after the end of the building’s or district’s life.

2.2 Characterisation of the energy demand in districts

After spatial delimitation and the definition of system boundaries, the characterisation of the energy demand is an important starting point for a holistic view of energy systems in the district. The following KPIs for demand can be derived from Table 4.

To characterise these energy uses in the district, individual uses can be distinguished according to the form of final energy used or assigned to specific use groups – the *sectors*.

To avoid the overlapping of different sector concepts, a distinction is made between end-use sectors and energy sectors. The U.S. Energy Information Administration defines end-use sectors as households, CTS, industry and transport. The concept of sector coupling, however, mainly refers to the synergies between energy sectors. In a broader definition, sector coupling also applies to the end-use sectors to untap synergies between parallel infrastructures between the sectors.

The energy sectors can usually initially be classified based on the energy forms of electricity, heating and cooling that determine most districts. However, it becomes apparent that this division must always be thought of in the local context of a defined district. Heating and cooling can be further separated into temperature levels as well as use types. Other energy sectors include transport and gas infrastructure, if present in the district. Gas has always mainly referred to natural gas, but higher proportions of hydrogen, not to mention hydrogen gas infrastructure, are possible in the long term. Transport is both an energy as well as a use sector.

This link between the energy sectors of electricity and transport shows that, in principle, the electricity sector almost always plays a central role in sector coupling. This is also reflected in the much-discussed concept of Power-to-X. The X represents various other sectors that, for example, can meet their own energy needs via a link to the electricity grid while simultaneously offering flexible grid services under intelligent regulation, linking them to the electricity sector. Examples of such power-to-X applications are power-to-heat, power-to-gas or power-to-liquid. In the latter case, a link to the chemical industry is established in addition to the defined energy sectors. However, these processes are generally not directly linked to the entire district but to individual end users represented by companies or clusters.

Type	KPI	Unit
Measured consumption	Energy demand Max. load	[kWh] [kW]
Calculated demand	Spec. demand/ consumption Spec. demand/ consumption Spec. demand/ consumption Spec. load	[kWh/m²a] [kWh/ person*a] [kWh/ process] [W/m²]

Table 4: KPIs for energy demand

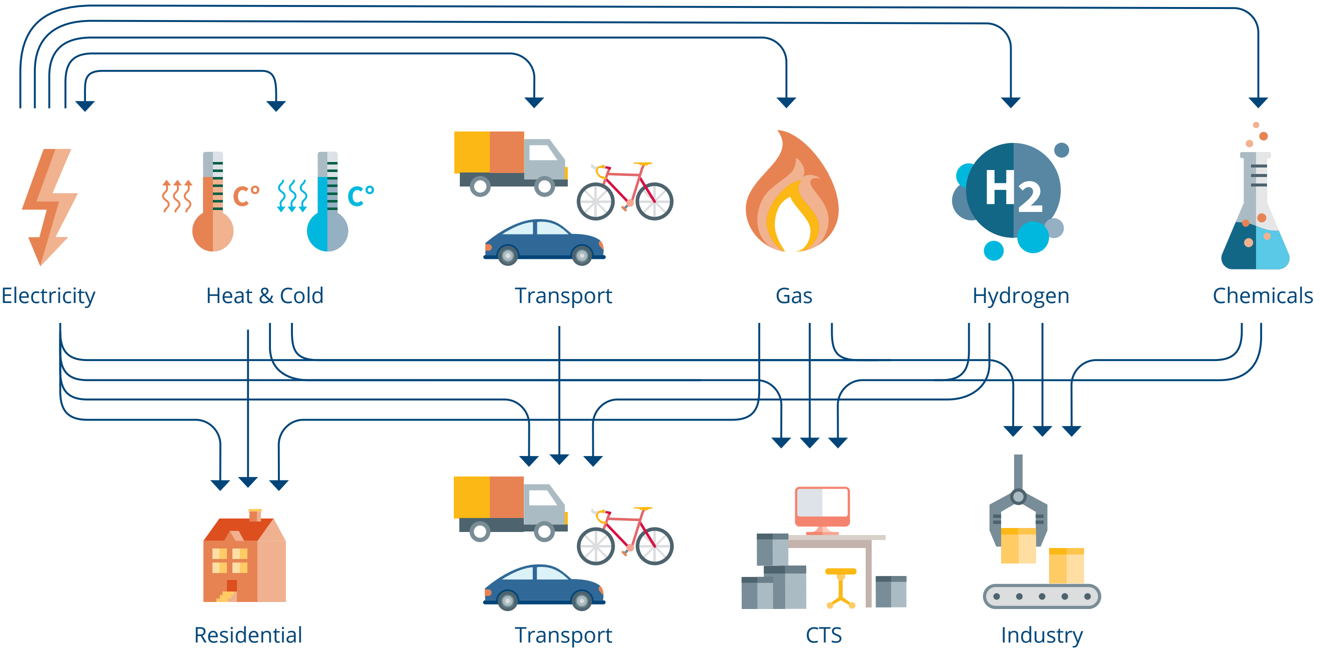


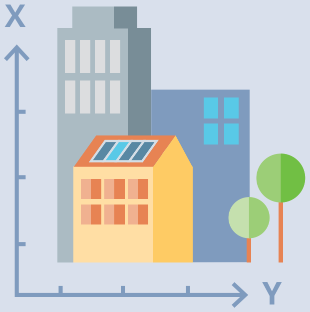
Figure 3: Interconnections between energy sectors and end-use sectors

Figure 3 shows the various interactions between energy sectors and end-use sectors. Power-to-X technologies play a crucial role here, further underlining the importance of the electricity sector in district development. The various interdependencies lead to a selection of important questions to be answered by the district developer. The necessary effort for such a holistic view can be justified by the many synergies that can be worked out from this complex interplay.

As the first guide to the search for such synergies, the following Figure 4 shows examples of reference load curves for different energy sectors broken down by end-use sector (households, CTS and industry), derived from considerations of Gobmaier, Corradini and Kraus (2007). It becomes clear that a more exact consideration of different aspects, such as heating, domestic hot water preparation and cooling, can be helpful for the heating sector. Moreover, the different patterns show that a breakdown of energy demand by use sector can be helpful if the temporal patterns are different. In addition, the different patterns show that it can be helpful to divide energy demand by use sector if they are different. Doing so makes the synergies of combined energy systems visible. More in-depth sector coupling can further optimise the operation of the energy system.

Modelling and simulation in district development

Various energy sectors, end-use sectors and industries need to be involved in holistic planning, making the close synchronisation of planning and development a useful strategy. Digital twins can support this process by data aggregation, simulation and subsequent optimisation of scenarios. At the same time, scalability and modularity need to be considered to avoid lock-ins and create interconnections for unknown events, processes and even technologies.



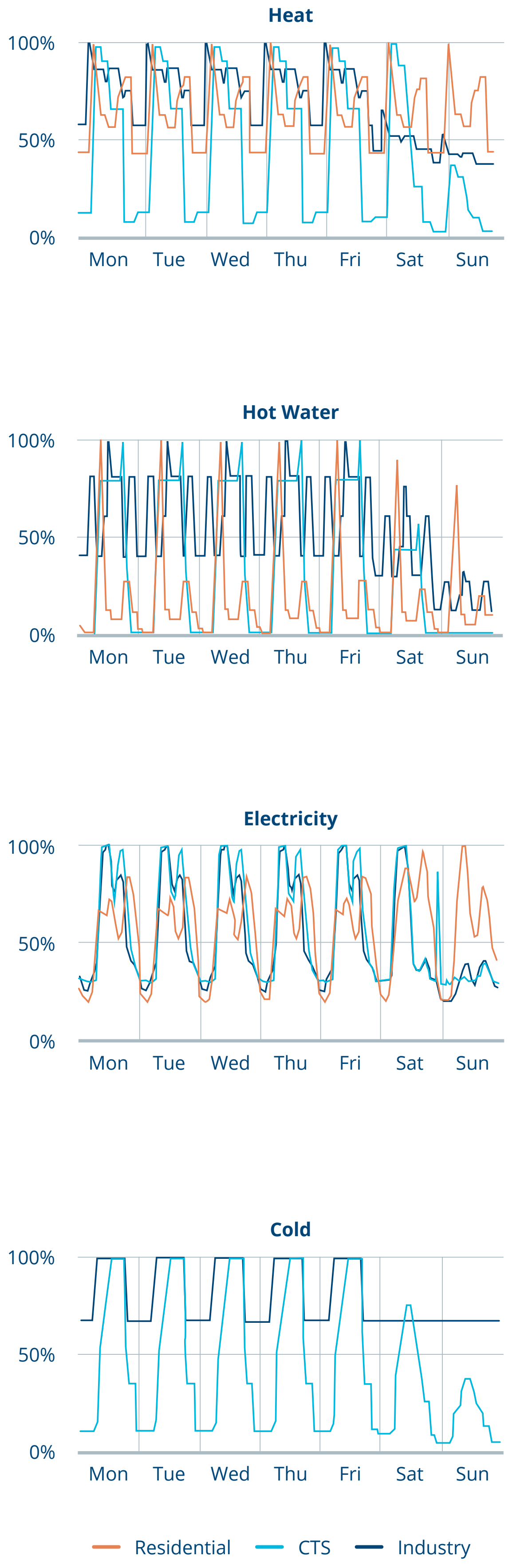


Figure 4: Load curves for heating, warm water, electricity and cooling across the residential, CTS and industry sectors

2.3 Local energy conversion in energy districts

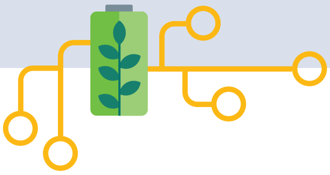
Until now, energy conversion along the process chain for energy carriers has taken place outside the district. Integrated district planning is moving energy conversion into the district.

This has already made it clear that the energy conversion process chains can go far beyond local district boundaries. Nevertheless, integrating local energy sources and local energy conversion is highly important for developing future district projects. Here, the concept of 'local energy source' or 'local energy conversion' means that the primary energy is transformed in the district itself. The following KPIs for the supply of energy can be derived from Table 5:

If the requirements from the previous section on local production are compared with real data, it becomes clear that local energy demand and production do not always overlap due to the weather dependence of renewable energies and consumption patterns. On the one hand, this clearly shows that energy-efficient districts need to store energy in order to shift energy; on the other hand, energy districts have multimodal energy systems, i.e. several energy converters, that complement each other. This is further specified in steps 7 and 8.

Missing harmonisation of the regulatory framework

In practice, the regulatory framework is a major obstacle to the more widespread implementation of multimodal energy systems and thus the climate-neutral transformation. Firstly, the lack of definitions, standards and technical requirements hinders the development of climate-neutral developments. Secondly, the current regulation of grid fees, surcharges and taxes disadvantages sector-coupled and more complex energy systems compared to fossil energy systems. Various sectors, such as heat, electricity, gas and buildings, are regulated at different policy levels (municipal, regional, national), further exacerbating the issues of contradictory legislation and pricing. For an integrated district with different types of energy conversions between energy and end-use sectors, it is crucial that the regulatory framework be amended.



Type	KPI	Unit
GHG potential	Spec. CO_2 emissions	[$kgCO_2eq/kWh$]
	Spec. CO_2 emissions	[$kgCO_2eq/process$]
Energy supply	Energy production	[kWh/a]
	Max. generation	[kW]
	Spec. generation	[kWh/m^2a]
	Spec. generation	[W/m^2]
	Primary energy factor	[ ]
Energy supply costs	CAPEX	[€/kW]
	OPEX	[€/kWh]

Table 5: KPIs for local energy conversion

Showcase: Meldorf-Nord and SmartQuart in Germany

An (energy) district is free to choose its balance boundaries and limits. This is exemplified by two district projects: Meldorf-Nord and SmartQuart.

Meldorf-Nord is a district in Schleswig-Holstein where waste heat from a printing company provides warm water heating for the public pool. After this initial partnership, 14 additional public buildings were added as anchor customers to the expanded heat grid. Subsequently, another 90 houses were connected to the heat grid. Physical conditions on the ground delimit the balance boundaries, which moved from the initial heat generation point in the printing plant and the heat sink in the public pool to a broader area, including the nearby residential areas, as the project progressed. The district's focus is on the energy supply in the heat sector without broader considerations in the electricity and mobility sector. Various additions, such as solar thermal installations and seasonal heat storage, have been added gradually to the existing energy system. Public buildings serve as anchor customers that provide the necessary guaranteed heat demand to set up the heat grid, which allowed residential areas to connect to the existing partnership.

On the other hand, SmartQuart connects multiple districts virtually. Here, the districts of Bedburg, Kaisersesch and a new district in the city of Essen are coupled virtually, and one district's energy surplus is accounted for in another. All three districts have distinct characteristics: a wind park with electricity storage and a LowEx-heat grid in Bedburg, a rooftop PV system with electric storage in Essen and a wind park combined with hydrogen production facilities and grids in Kaisersesch. All the districts are connected via a cloud, ensuring climate-neutral operation across all three districts jointly. The electricity sector is the starting point for further application in the heat and mobility sector, as it is a source of renewable energy production measured in real-time. Among the stakeholders, an integrated energy utility and grid operator centralises the control and operation of the various technical installations. Partnerships with the respective cities are necessary for support with the establishing installations as well as administrative issues. Various smaller companies act as component suppliers.

More information

Takeaway:

There is no uniform definition or distinction of the term energy district. A district's balance boundaries (both temporal and local) must be defined in the district project initiation phase.

From the different trajectories of the different energy sectors, which in turn are composed of different shares of the respective use sectors, it is clear that sector coupling in the district can help approach optimised energy system operation. This becomes especially important if energy consumption is increasingly covered by renewable energy sources. Therefore, an exact characterisation of the energy requirements in the district is an important step to develop the best possible energy system configuration for a district.

Conversion chains in climate-neutral districts are becoming more complex due to sector coupling and subsequent electrification. Furthermore, the lacking simultaneity between generation and demand increases the need for storage and multimodal energy systems. Local energy infrastructures, such as heat grids and stable electric distribution networks, support these decentralised multimodal energy systems as their specific investment costs decrease with the size of the installations.

Step 3: Green and sustainable financing

After defining the district's balance boundaries and areas of action, it is useful to consider green finance options as project developers can benefit from attractive financing options. The KPIs derived from the financial instruments and green finance taxonomies can be used to configure the energy system. Section 3.1 provides the political background of green finance, with its main risk assessment characteristics described in section 3.2. The EU taxonomy is explained in section 3.3 before a presentation of specific financial instruments in section 3.4, followed by a description of the current situation of green finance in China in section 3.5. A projection of future developments is provided in section 3.6.

3.1 In short: What is 'green finance'?

Green finance derives from Article 2.1c of the Paris Agreement and has been further specified in recent years. (European Union, 2016) This also affects district development with respect to both the energy system and sustainability. The topic of green finance has since been gaining momentum. Capital flows must be redirected towards sustainable investments to achieve the goals set by the Paris Climate Agreement and the UN Sustainable Development Goals (SDGs). Therefore, the financial system plays a major role in the transformation to a low-emission, resource-saving and social economy. The term 'green finance' is used increasingly, in addition to the term 'sustainable finance', which includes green finance but covers a wider scope. However, there is no official definition of these terms, and they are often used synonymously depending on the context and institution, as shown in Table 6.

European Commission	Sustainable finance refers to the process of taking environmental, social and governance (ESG) considerations into account when making investment decisions in the financial sector, leading to more long-term investments in sustainable economic activities and projects. In the EU's policy context, sustainable finance is understood as finance to support economic growth while reducing pressures on the environment and taking into account social and governance aspects (European Commission, n.d.).
German Federal Government	Taking sustainability aspects into account when making decisions on the financial market. In addition to climate and environmental protection (green finance), sustainability is also understood to include economic and social aspects (ESG approach) (Die Bundesregierung 2021).
People's Bank of China (PBOC)	Green finance refers to a series of policy and institutional arrangements to attract private capital investments into green industries – such as environmental protection, energy conservation and clean energy – through financial services, including lending, private equity funds, bonds, shares and insurance (Choi & Heller, 2021).

Table 6: Overview of definitions for sustainable and green finance

3.2 A key aspect of (green) finance: assessing risks and potentials

Financial institutions are increasingly taking environmental, social and governance (ESG) risks into account when assessing their clients, considering what physical and transitory climate risks could negatively impact the client's current and future business model and what opportunities could arise as a result. Moreover, financial market participants (e.g. financial institutions, asset managers) are increasingly including the impact of climate-relevant aspects in their decision-making processes and the assessment of companies and/or projects.

There are two types of risks: Physical climate risks and transition risks. Physical risks are risks that arise due to events (acute) or longer-term shifts (chronic) in climate patterns and include extreme weather events, such as droughts, tropical cyclones, sustained higher tempera-

'Green finance' in theory and practice

Even though the term 'green finance' is used in various contexts, there is a lack of a common definition. Results from a poll conducted in our workshops showed that many people have heard of it; however, they don't necessarily use or apply instruments associated with green finance or the associated requirements (for example, sustainable reporting requirements for companies). Moreover, the EU action plan and its instruments have not completely reached every company so far, making it all the more important to create a broad understanding of the topic and its application.

tures, rising sea levels, fires, and biodiversity loss. On the other hand, transition risks are caused by political, legal, technological and market-specific changes that arise during the transition to a lower-carbon economy (Bloomberg, 2017).

For companies seeking financing, this means increased requirements for disclosing climate-relevant information and an increased commitment from the financier regarding the underlying project. For this reason, it is necessary to consider potential financing conditions at an early stage and integrate them into the planning process.

More and more, financial system representatives see themselves playing a more active role in the transformation to climate neutrality via the following transmission channels: risk management, cost of capital, exposure, provision of liquidity and spill-over effects.

Several regulations and policy decisions drive this development: In December 2019, the European Commission published the Green Deal – a growth strategy that aims to make Europe the first climate-neutral continent by 2050 (European Commission, n.d.-a). In addition to finance, buildings, energy production, energy efficiency and sustainable mobility, among others, appear as supporting elements in the Green Deal.

Furthermore, the European Commission published a key document in spring 2018: the Action Plan on Financing Sustainable Growth. This action plan identifies three main objectives necessary to implement sustainable finance:

1. Reorient capital flows towards sustainable investments to achieve sustainable and inclusive growth
2. Manage financial risks that arise through climate change, resource scarcity, environmental degradation and social problems
3. Foster transparency and long-termism in financial and economic activity

To achieve these goals and develop recommendations for implementation, the EU established the Technical Expert Group on Sustainable Finance (TEG), which brought together experts from different disciplines. They completed their work in spring 2020, and their proposals have been translated into legislation.

The multitude of actions shows that sustainable finance has become a core element of the sustainability transformation and should no longer be ignored by banks or the real economy.

3.3 The EU taxonomy

The EU taxonomy is a fundamental tool for achieving these goals. It is a classification system for environmentally sustainable economic activities. The terms 'sustainable' and 'green' have always been subject to different interpretations, creating space for so-called 'greenwashing'. A uniform definition of environmentally sustainable economic activities based on scientific findings creates a common understanding among all economic participants, fair competition and, above all, provides certainty for investors. The EU taxonomy provides a common understanding of which economic activities need to be considered environmentally sustainable. It is important to note that it does not aim to dictate or judge investments. Projects or companies that are not taxonomy compliant can still receive funding and should not be considered 'brown' activities and/or companies. The primary issues are:

- to reassure investors that financial products declared as green meet standardised sustainability criteria and
- to raise awareness of the environmental impact of financial products.

The EU taxonomy aims to make the EU's environmental goals understandable and, most importantly, tangible and measurable for financial market participants (and other stakeholders). Economic activities must now be assessed using clear data-based, technical screening criteria (e.g. CO_2 emissions/kWh, compliance with international standards). In this way, environmental goals can be considered in strategies, investments and lending decisions.

Evaluation scheme of the EU Taxonomy

Four conditions (cf. Table 7) must be worked through sequentially when assessing an economic activity. If the activity does not fulfil one condition, it must be classified as 'not taxonomy compliant'. Only after all four conditions have been fulfilled is an economic activity considered EU taxonomy compliant. However, the non-fulfilment of the criteria does not mean that green financial products cannot be used.

The EU taxonomy methodology

The EU taxonomy was developed in accordance with the EU's six environmental objectives:

1. Climate change mitigation
2. Climate change adaptation
3. Sustainable use and protection of water and marine resources
4. Transition to a circular economy
5. Pollution prevention and control
6. Protection of healthy ecosystems

For an economic activity to be classified as environmentally sustainable (according to EU taxonomy), the four key conditions listed in Table 7 must be met.

So far, the criteria have only been elaborated in detail for objectives 1 (climate change mitigation) and 2 (climate change adaptation). If it is a complex project, such as a district, or a company with several divisions and areas of activity, all economic activities are considered individually and aggregated at the end of the assessment.

Application of the EU taxonomy

According to the EU Taxonomy Regulation, the following stakeholders need to apply the EU taxonomy:

- Financial market participants offering financial products to the EU
- Large companies that need to make a non-financial declaration according to the Non-Financial Reporting Directive
- EU member states

Companies not covered by the Non-Financial Reporting Directive (NFRD) or Corporate Sustainability Reporting Directive (CSRD) may also use the EU Taxonomy to help develop their sustainability strategy and benefit from the low-cost financing offered by green finance products. Another motivation might be the use of taxonomy compliance for marketing purposes to attract investors.

Financial market participants and large companies must disclose the proportions of sales revenues, capital expenditure (CAPEX) and operational expenditure (OPEX) associated with environmentally sustainable economic activities. If financial products are advertised with environmental characteristics and features, the distributing institutions shall indicate to which extent the assets underlie the financial product and represent environmentally sustainable economic activities according to the EU taxonomy. EU member states must refer to

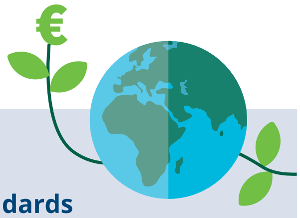
Substantial contribution	The economic activity makes a substantial contribution to the achievement of one or more of the six environmental objectives.
Do No Significant Harm (DNSH)	The economic activity does not lead to significant harm to one or more of the six environmental objectives.
Minimum social safeguards	The economic activity complies with the established minimum social safeguards (OECD Guidelines for Multinational Enterprises and United Nations Guiding Principles on Business and Human Rights, including the International Labour Organisation (ILO) Core Labour Standards and the International Bill of Human Rights).
Compliance with the technical screening criteria	The economic activity meets the technical screening criteria for the respective environmental objective.

Table 7: Key conditions of the EU taxonomy

the EU taxonomy in future national measures to promote environmentally sustainable financial products.

3.4 Sustainable finance solutions

Several sustainable finance products have emerged on the financial market in the context of these political and social developments. These products are based on traditional financing mechanisms and are complemented by the inclusion of sustainability criteria.



Sustainable finance standards

Even if recognised international process guidelines exist for sustainable finance products (e.g. green bonds, social bonds, sustainability-linked bonds), they can be structured differently in individual cases.

ICMA Green Bond Principles

The ICMA Green Bond Principles (GBP) are voluntary guidelines for the issuance of green bonds. They are intended to promote integrity in the green bond market through transparency, disclosure and reporting guidelines. They aim to assist investors by ensuring the availability of information necessary to assess and evaluate the environmental impact of the issuance (International Capital Market Association, 2020).

The four core components of the GBP are the use of the proceeds, the process for project evaluation and selection, the management of the proceeds and finally, reporting.

CBI Climate Bond Standard

The Climate Bond Standard was developed by the Climate Bonds Initiative (CBI) and is a globally used and recognised standard for the issuance of green bonds. In addition to a solid Green Bond Framework, reporting requirements and detailed expenditures and debt instrument definitions, CBI also provides a Climate Bond Certification scheme, which is carried out by a third-party verifier. This certification provides “assurance for issuers and investors that a green debt product meets labelling requirements for major global jurisdictions is science-based and is aligned with the goals of the Paris Climate Agreement to limit warming to under 2 degrees” (Climate Bonds Initiative, n.d.).

As already mentioned, projects that do not meet sustainability criteria are not categorically excluded from financing by these regulations (such as the Taxonomy Regulation or the Non-Financial Reporting Directive). Sustainable finance aims to enable a transformation towards a more sustainable economy, which includes promoting economic activities and companies that do not yet meet today’s criteria but have set ambitious goals to achieve such criteria by a certain date. Transformation cannot be achieved smoothly and efficiently with bans and strict funding freezes. Policymakers and financial sector participants are aware of this fact.

Sustainable financial products

In the financial market, there is a basic distinction between equity financing and debt financing. Equity financing mainly refers to financing through the sale of company shares (stocks). In the field of sustainable finance, there is no difference in the share as a financial product. Interested investors simply include additional information on the underlying business model in their investment decision. Debt financing, however, refers to the sale of debt instruments. In return for the loan received, interest must be paid to creditors (as well as the entire amount borrowed according to an individually regulated payment plan). Examples of such financial products are loans and bonds.

Green financial products, both loans and bonds, can be differentiated into ‘green’ or ‘sustainability linked’. These two terms refer to the use of the financial resources. As for green bonds, the issuer must ensure that the financing is matched by a CAPEX that provides defined ecological benefits. The funds can be used for various project categories defined as “green projects” (International Capital Market Association, 2021), such as renewable energies, clean transport or sustainable water management, that have an environmental benefit and are in line with specific environmental goals. Sustainability-linked bonds offer the issuer the possibility to link the issuance of the bond to transparent sustainability criteria. The bond funds can be used for general corporate financing and, in contrast to green bonds, are not earmarked for a specific purpose. The positive/negative sustainable development is assessed against measurable, material and ambitious KPIs in connection with sustainability performance targets. The achievement or non-achievement of the defined sustainability targets affects the financial characteristics of the bond.

Showcase: Europaviertel in Berlin, Germany

A new district focusing on sustainability and digital applications is being built close to Berlin's central train station. What makes this project special is that the financing is based on green bonds in addition to the single large investor. The green bond programme is organised by the LBBW, the regional state bank of Baden-Wuerttemberg.

To be included within a green bond, the EU taxonomy criteria must be met. Final energy demand, CO_2 emissions, waste disposal from all life cycles, etc., are considered necessary performance indicators. This approach led to some innovations, such as the provision of building materials via rail instead of road transport. Regarding data collection, certification by the German Sustainable Building Council (DGNB) was helpful as many performance indicators are already collected and adjusted there.

The district is a mixed-use area for living, commerce and offices on land that had been converted from its former use as railway land. Building standard KfW-55 (energy-efficient construction) applies, and heat is provided via a district heating system with multiple decentralised combined heat and power (CHP) stations.

Sustainability and digitalisation are key action areas for the project developers as the real estate market demand for sustainable buildings increases. At the same time, banks and investors are evaluating their portfolios and sustainability to conform with ESG and EU taxonomy criteria to avoid stranded assets, which brings new financing vehicles to the market.

More information
(in German)

3.5 Sustainable finance in China

As one of the world's largest economies, China plays a significant role in global climate change efforts. Years ago, China already took measures to fight high levels of air pollution in its cities and regions.

Therefore, the motivation to promote green finance did not arise from the Paris Climate Agreement as it did in Europe. On the contrary, it came from the practical need to improve air quality. However, since September 2020, CO_2 emissions have also played a major role. At that time, President Xi announced China's goal of reaching climate neutrality by 2060, with an emissions peak by 2030.

Regulatory developments

China already has many years of experience with green finance and often leads statistics on sustainable finance volumes. This is partly thanks to the Chinese Central Government, which plans the Chinese market, including financial flows, and partly due to its own definition of 'green', which is broader than the EU's definition.

Several guidelines exist to channel financial flows into green projects and prevent highly polluting projects (as defined by the Chinese government). These guidelines include the Green Credit Policy (2007), the Green Credit Guidelines (2012) and the China Banking Regulatory Commission's Notice on KPIs for Green Credit Implementation (2014). Finally, in 2016, the Chinese government issued its Guidelines for Establishing a Green Financial System.

The Green Bond Endorsed Projects Catalogue (2021 Edition) represents China's taxonomy, defining which projects and industries are considered green. Prior to the 2020 revision, there were three different national standards, which caused uncertainty among international investors due to inconsistencies.

At the European level, the overarching goal is to transform the economy so that it moves along a path that enables the continent to be climate neutral by 2050 without violating other environmental goals. Until its revision, the goal of the Green Catalogue was to strengthen industries declared to be 'green' and prevent pollution. Therefore, the catalogue represented a list of industries and projects that were considered green per se.

China's international engagement

In recent years, collaboration has increased between the Chinese government and other international initiatives, many of which aim to harmonise standards and seek synergies between individual efforts. These collaborations include:

- Co-chairing the G20 Green Finance Study Group (2016–2018)
- Participating in the Network for Greening the Financial System (NGFS) as a founding member (2017–)
- China-UK Economic and Financial Dialogue
- The People's Bank of China (PBC) joined the International Platform for Sustainable Finance (IPSF) (2019–)

This development shows that China is interested in an interlinked green finance regulatory framework in which international investors usually have confidence.

Green bond / Green loan market

In published graphs, China repeatedly tops the list of issuers of green bonds. China is also often referred to as the leading country in the field of green finance. It is important to mention that the definition of green and other requirements for green financial products are decisive for the extent to which these products are used. A loose and easily fulfiled definition, as well as voluntary reporting and little proof of how the proceeds are used, might lead to increased activity in this market in general.

Even though the green catalogue has been slightly modified and the criteria have become stricter, it is important when interpreting the graphs to understand the criteria that applied up to July 2021. As described above, projects and companies were considered green if they were active in a sector defined as green. Until July 2021, this also included the efficient use of fossil fuels. Similarly, according to the standards, 50% of the proceeds from green bonds could be used as working capital (OPEX), and their exact use did not have to be proven. Likewise, there were no consistent disclosure requirements on how the funds were used. Since 2016, China has been one of the largest issuers of green bonds worldwide. At the same time, only half of China's green bonds were compliant with the widely recognised CBI standard (Climate Bonds Initiative & SynTao Green Finance, 2020). In 2020, the volume fell for the first time since 2015 due to the global pandemic.

In the past, most green bonds in China were issued by state-managed banks. Even though the share of non-financial corporations among the issuers has been rising sharply for some time now, the issuance of green bonds is characterised by a very strong public sector. Looking at the use of the proceeds, it is clear that funds raised via green bonds were primarily used for sectors such as clean transportation, clean energy and pollution prevention and control.

As with green bonds, developments in green loans over the past few years have been very positive. The annual growth rate of green loans is about 14%, which is significantly higher than the growth rate of traditional loans. This is due to the large number of subsidies and incentives. The Chinese government offers many supportive measures, such as the inclusion of green finance performance in the macro-prudential assessment of banks, interest rate subsidies from local governments, government promotions and capacity-building actions, to name a few. Such measures ensure strong growth. And despite the expansive issuance of green loans, their quality has not suffered from that growth (e.g. the non-performing loan ratio has remained constant).

3.6 Future of green finance

This chapter has shown that there is momentum in sustainable finance. Governments are increasingly ensuring a good basis for further growth in this sector: clear goals, strategies, standards and a stable regulatory framework. But the financial sector itself has also become more active. It has switched from a wait-and-see attitude to a more proactive one and wants to help shape and define developments.

It is to be expected that the Chinese government will continue to harmonise its national standards with internationally applicable principles and standards. The revision of the Green Catalogue was the first and major step in this direction. China's participation in various international platforms and working groups shows that this process is not yet complete and that further adjustments will follow.

On 6 July 2021, the European Commission presented its *Strategy for financing the transition to a sustainable economy.* This strategy is built on the Action Plan on Financing Sustainable Growth and specifically addresses the economy's transition towards more sustainability in the context of the COVID-19 pandemic, placing a special focus on the fact that the path to greater sustainability also requires investments that finance transformative activities. This necessity is of great importance for a long-term perspective since such activities were still underrepresented in the previous version of the taxonomy.

The European Commission also announced that the existing EU taxonomy will be broadened. For example, energy sector criteria will be adapted, and the taxonomy will be expanded to include the agriculture sector. The strategy also states that by the beginning of 2022, the technical assessment criteria for the other four EU climate targets (water, circular economy, pollution prevention and biodiversity) will be developed. In the meantime, a report on the potential social taxonomy will be published. The EU will develop more labels and standards for sustainable financial products to prevent greenwashing and create more trust among investors. In addition to the Green Bond Standard as the gold standard, additional transition or sustainability-linked bond labels are also envisaged.

The German Federal Government also published its own Sustainable Finance Strategy in May 2021 (Die Bundesregierung, 2021). This strategy is based on the recommendations of the Sustainable Finance Advisory Council. The Federal Government intends to use this strategy to position Germany as a leading hub in the field of sustainable finance. The proposed measures include a sustainability traffic light system for investment products, the strengthening of green bonds, more transparency regarding federally owned capital investments and the enhancement of corporate reporting.

This transformation will affect more than large individual and intrinsically motivated companies. ESG criteria will play an increasingly important role in future financing, and every stakeholder should address this in good time. Finally, this criterion should not be seen as an obstacle and a difficulty but as an opportunity. Essentially, everyone should have their own intrinsic interest in adequately addressing climate risks. Sustainable finance products provide solutions to fund the transition towards a sustainable economy.

Takeaway:

The analysis of risks and opportunities forms the core of (green) financing: Green finance makes it possible to ascertain and assess environmental, social and governance criteria. So far, policymakers are the decisive force for communicating on the abstract and overarching topic of 'green finance'. This applies to both China and the EU, although the market for green bonds is larger in China due to its broader definition. Also, the instruments are becoming more standardised and made comparable through new legislative programmes (e.g. the EU taxonomy) or private initiatives (e.g. assessments of climate bonds). Many green finance instruments and products already exist today, and financial volumes are constantly increasing. Therefore, financial players increasingly see the benefit of selling green finance products, while companies are bound to 'green' principles via indirect regulations (such as the disclosure of investments).

Step 4: Energy concept I: Characterisation of the energy demand

Buildings and their respective uses form the basis for the energy demand in districts. The energetic quality of buildings and the usage patterns are decisive for energy supply concepts in those districts. Buildings and users can be understood as their smallest unit, within which there are different possibilities for the distribution and conversion of energy. This chapter first provides insight into the final energy usage for the four end-use sectors (Section 4.1) as an overview before briefly looking at the developments in the area of electricity demand (Section 4.2) in districts. Energy demand in buildings (Section 4.3) is brought into focus, and then, finally, the synergies between buildings in the district are considered (Section 4.4).

4.1 Energy usage by sector

Figure 5 shows the distribution of final energy consumption for the four end-use sectors based on data for Germany in 2019 (AG Energiebilanzen e.V. (AGEB), 2020). These distributions show that the classification into end-use sectors represents fundamentally different energy use patterns and corresponding energy carriers. While the final energy use in the residential sector shows a very large share of heat consumption to meet the demand for heating space and domestic hot water, other sectors show larger shares of mechanical energy and, especially for the industry sector, high demand for process heat. The higher share of primary industries in the industry sector leads to higher demand for process heat than mechanical energy. Compared to Germany, it must be considered that due to the different climate zones in China, very high demand for colling energy exists for all user groups. Even in areas as far north as Beijing, air conditioning is commonly used for 4–5 months in all building types (residential, office, commercial, industrial, transportation, etc.). On the other hand, more than half of the country has no winter heating.

Future outlook regarding demand

Various factors affect energy demand. Externally, climate change leads to higher average temperatures while increasing the likelihood of extreme temperatures and weather events. Cities are subject to a higher increase in temperatures compared to the global average, resulting in higher demand for cooling and reduced heating demand. Residential and commercial buildings are more affected because they represent a larger share of the demand for low-temperature heat. Additionally, many existing buildings are not designed to cover the higher demand for air-conditioning or cooling.

Therefore, it stands to reason that it would be useful to consider the demand patterns of the various end-use sectors at an early stage of designing the district energy system. Doing so can lead to synergies and potential for saving energy, e.g. considering the waste heat from process heat consumption in industry as a low-temperature heat supply for the space heating demands in modern residential buildings.

Additionally, the definition needs to consider existing urban land use planning and policies for a compact and mixed-use urban environment. If the local authority has not established and defined guidelines, they must be

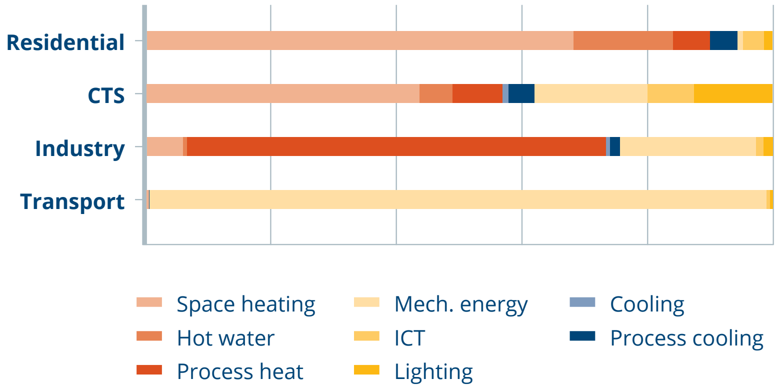


Figure 5: Distribution of final energy uses for various end-use sectors in Germany

developed to help other stakeholders choose their optimal heating system and renovation strategy. Not only will doing so help to reduce mobility needs, but it will also maximise the use of local climate-neutral energy potential.

4.2 Electricity demand in buildings

While Figure 5 approaches the final energy demand by sector from the perspective of different final energy use types, another useful perspective is to consider the use of different forms of energy by sector. In this context, the electricity demand patterns by sector are of particular interest because electrification is generally seen as a promising strategy for decarbonising district energy systems (which is further discussed in step 6). Figure 6 shows the share of electricity in the final energy consumption by sector for Germany based on the same 2019 dataset by AGEB (2020), providing an initial overview of the role of electricity in today's energy system. The commercial, trade and services sector already uses electricity to cover almost 40% of the final energy consumption; the shares in the industry and residential sectors remain lower. Despite the electric vehicle trend and the corresponding charging infrastructure, electricity still only accounts for 1.6% of the final energy consumption in the transport sector.

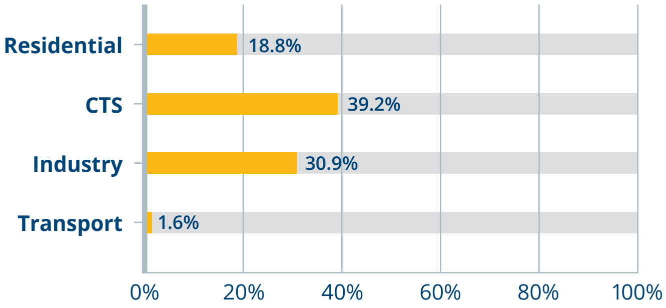


Figure 6: Shares of electricity in the final energy consumption by sector for Germany in 2019

Across the residential, CTS and industry sectors, the final energy use types with the highest shares of electricity of up to 100% are process and space cooling, information and communications technology (ICT), and lighting. On the other hand, the shares of electricity to provide the different types of heating range from around 7.5% for the industry sector up to around 10% for the commercial and residential sectors. These figures illustrate both the tremendous potential and the huge challenges for the electrification of the heat supply, which also has a large share of the overall energy consumption in Germany.

4.3 Thermal energy demand in buildings

In order to consider the heat transfer in buildings when planning district energy systems, certain parameters, listed in Table 8, need to be taken into account.

Type	KPI	Unit
Thermal energy balance of buildings	Heat transfer coefficient	[W/m²K]
	Building air-tightness n_{50}	[1/h]
Building heat transfer system	Heating/cooling load	[kW]
	Temperature of the heat/cooling transfer	[K]

Table 8: KPIs for thermal energy demand and heat transmission systems

An essential purpose of buildings is to provide people with a safe and comfortable place to be (mainly sheltered from the external environment). Studies suggest that people spend about 90% of the day indoors. An important component is the provision of thermal comfort for the building users. A person's thermal comfort can be modelled using a simplified heat balance, in which the heat gains from the person's metabolism compensate for the heat losses via the skin and breathing air. If the person's heat losses are greater, they perceive their thermal comfort as cold; if the heat losses are lower, their thermal comfort is perceived as too warm. Five different factors significantly influence the thermal comfort of humans:

- Operating temperature consisting of
  - Air temperature
  - Average radiation temperature of the free surfaces
- Air velocity
- Humidity (relative humidity)
- Clothing
- Degree of activity/metabolic rate

Three of the five parameters relate directly to environmental conditions. In enclosed spaces, the environmental conditions are in turn influenced by the energy and mass balance in a room. The energy balance of a building consists of transmission heat losses (i.e. heat losses via the building's facade), ventilation heat losses (i.e. heat losses due to air exchange), solar and internal gains (e.g. from waste heat from electric devices or the person themself). Various structural components are responsible for the building's overall heat losses. The share in total heat losses for each component in an average non-refurbished building is provided in Table 9.

Building component	Heat losses [%]
Heating system	20–30
Roof	15–20
Ventilation	10–20
Windows & doors	10–15
Walls	30–35
Building ground	5–10

Table 9: Ranges of heat losses by building component

The three most important factors of a building’s energy efficiency are its physical structure, architecture and use. The building’s physical structure includes the wall structure (e.g. heavy or light construction) as well as the insulation properties (defined using thermal transmittance) of the walls, roofs, floors and windows. In addition to the construction, airtightness is another important factor in the construction of a building. The air exchange rate for determining the degree of leakage is called n50 and indicates how often the air in a building is exchanged between the inside and the outside at a defined pressure (dP = 50 Pa = 0.0005 bar). Modern buildings have air exchange rates of 1.0 to 2.0 1/h; passive houses must have n50 > 0.6 1/h. For old buildings and non-professionally operated buildings, this value can rise to 12.0 1/h. The architecture of the building includes the proportion of window space, thermal bridges and the ratio between the outer wall surface and the volume of a single building (see step 4). The proportion of window space determines the solar gain of a building. Thermal bridges promote heat conduction from the inside out. Examples are balconies, which are directly connected to the masonry along their entire length. The surface-to-volume ratio is also essential for heat losses. Moreover, the use of the building has a major effect on its energy balance (see step 4). The use determines the comfortable or required room conditions due to different temperatures and a varying need for air changes.

The design of the heating and cooling system depends on the system’s required heating and cooling power. Typically, the maximum heating power for the building is given as a function of the energy balance and the outdoor temperature, shown in a simplified form in Figure 7. This function makes it possible to derive parameters needed to configure the entire energy system. First, the maximum needed power at the lowest design temperature (which depends on the region in question) and second, the temperature at which no heating power is needed. The constant power above that temperature shows the possible need for domestic hot water in the building. Depending on the internal and external gains, as well as the building’s insulation (i.e. heat losses), the function may shift (see dashed lines). The power needed correlates directly with the cost of the energy system.

In addition to the system’s power and the energy provided over the year, the necessary supply temperatures for heating or cooling are decisive in designing an energy system. This is particularly important for existing build-

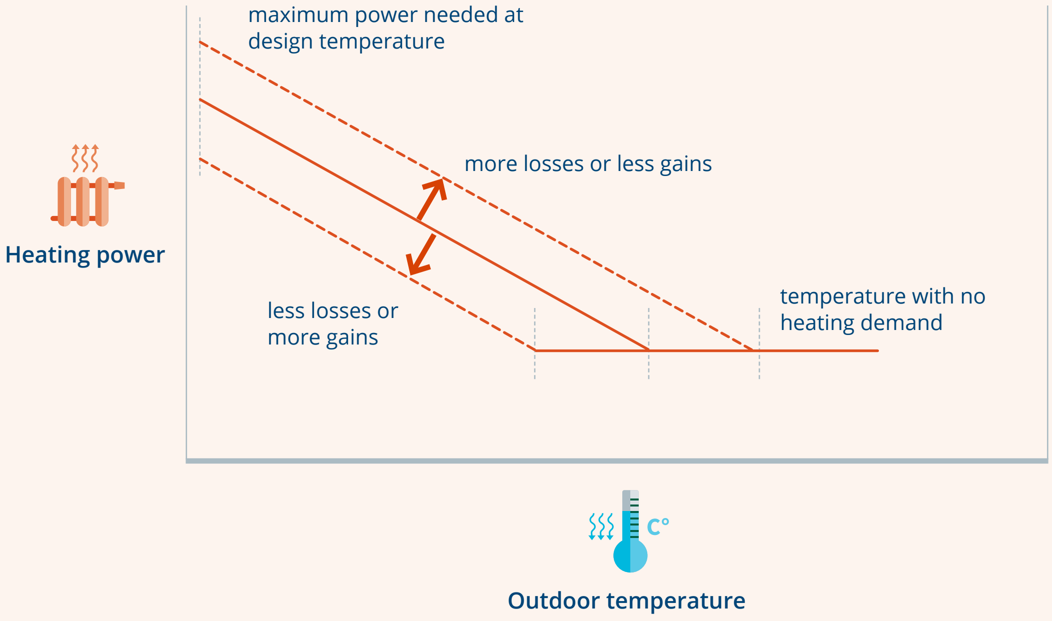


Figure 7: Relationship between the outdoor temperature, heating capacity and internal loads/losses

ings that are to be integrated into the district energy system. The temperature determines not only the necessary supply temperature of the energy system but also the size and structural design of the heat transfer system in the buildings.

The list shows various factors that affect the energy balance of a building. If the energy balance of a room is not balanced, additional energy is required to provide comfortable room parameters. The provision of additional energy necessary for thermal comfort (i.e. heating or cooling) can be introduced into the building in two different ways:

- Static heating/cooling: Heating or cooling via water-guided heat exchangers in the rooms
- Dynamic heating/cooling: Heating or cooling via ventilation with conditioned air

With static heating, heat transfer surfaces are installed in the room (e.g. radiators) through which warm water flows, heating the exchangers and releasing heat into the room. The same principle also works for cooling. The decisive degree of freedom for the heating performance of a static heating system comes from the surface area of the heat exchangers and the temperature difference between the heating water and the room. The lowest possible temperatures for the heating water optimise the efficiency of the energy conversion and distribution. Such systems are also called “LowEx” (low exergy) for keeping the exergy content of the energy introduced into the room as low as possible.

Due to the high necessary temperature differences, radiators are only partially suitable for cooling the room. The necessary low temperature levels raise problems such as the formation of condensation or even temperatures near the freezing point. Surface heating systems can also be used for cooling. The temperature differences between the cooling set temperature and the space heating temperature are usually less than for heating, which means that the energy output for cooling is lower.

Static heating/cooling systems are supplemented by indoor air technology systems: dynamic heating/cooling systems. The main difference lies in the transfer of energy into space. With dynamic systems, heating/cooling energy is introduced into the room via conditioned air (i.e. tempered air volume flow). Therefore, the transmitting medium is no longer water but air. The advantages include controlled compliance with a minimum airflow for fresh air supply and the possibility of introducing high cooling loads. In addition to the temperature, an indoor air technology system can be used to adjust other air quality properties, including humidity, CO_2 content (via fresh air supply) and the flow speeds in the room. Important operating modes are cooling and heating (temperature of the supply air and insertion of the heating and cooling load), as well as humidification and dehumidification (air treatment). Air treatment requires additional energy. For example, certain ventilation technology designs also require heating energy to dehumidify air in the summer.

The three most common ventilation system designs are:

- All-air systems
- Air-water systems
- Refrigerant-based systems

In all-air systems, both the temperature control and the air treatment (e.g. dehumidification) of the supply air are carried out centrally. The conditioned air is fed directly into the individual rooms via channels and no longer requires decentralised treatment. Air-water systems prepare the air centrally (e.g. dehumidification), but the supply air in each zone is subjected to a thermal post-treatment (e.g. heating or cooling), making it possible to implement zone or room-by-room settings easily. The third type of dynamic heating, refrigerant-based systems, can only be used to heat or cool; therefore, they cannot process the air.

The type and design of the heating-cooling transfer significantly affect the choice and design of the energy system, determining not only the necessary flow temperatures in the heating or cooling system but also the dynamics and the maximum performance. Static systems have longer reaction times than dynamic systems, particularly surface heating and thermal component activation, meaning that it may take several hours to reach a room’s modified target temperature. Indoor air systems react very quickly to a change in boundary conditions. Both systems are often combined, with static heating taking over the baseload and dynamic heating taking over the peak loads. The different time constants must be considered in the design and regulation of the energy system.

Showcase: Siemens Campus in Erlangen, Germany

Covering 54 hectares, Siemens Campus Erlangen was one of the largest office campuses in the world when it opened in 1965. In 2014, due to its age, Siemens decided to redevelop the area. Following an architecture competition, a design by KSP Jürgen Engel Architekten was selected for implementation. One of the conditions was to increase the flexibility: the building should have the same typology independent of the possible end users.

The new campus will include over 320,000 square metres of new office space and at least 100,000 square metres of new residential space, a hotel, as well as leisure, sports, restaurant, and shopping facilities. Construction has already

Heating demand	2.15 kWh/m²a
Final energy demand	17.43 kWh/m²a
Indoor temperature	20–26 °C
Indoor relative humidity	35–65%
Indoor carbon dioxide content	1000 ppm
The temperature difference between the inner surface of the enclosure structure and the indoor air is lower than	3 K

Table 10: KPIs for Shandong Vocational College

begun, and the first module for about 6,000 people is ready as of 2021. Construction of all seven modules should be completed by 2030.

Module 2 comprises five five-storey office buildings, including the central Siemens reception, and is currently under construction. It is Germany's largest hybrid timber construction project, using timber-hybrid prefabricated components from the Austrian company CREE. Siemens wants to use the same process to erect all five buildings. The next step would be to develop a new construction standard using hybrid timber as a material. Hybrid timber reduces CO_2 emissions by 80% and uses only one-third the amount of concrete. Moreover, wood elements create a special atmosphere, which increases the comfort of the employees working at Campus Erlangen.

Prefabricated hybrid timber modules are both economical and ecological. Plus, since they combine wood with other materials (e.g. steel, concrete and glass), the strengths of each material can be used to optimise structural and building performance. So while timber serves as a carbon sink, the reinforced concrete elements increase fire resistance. Timber and concrete parts have special patented connectors that minimise traction between the materials. Additionally, the mandrel bars sticking out of the downside of a wall element can match the holes in the cover plate below.

The development of the energy design is supported by the Siemens Digital Twin for Energy. A simplified model is available under https://eco-web.siemens.com/quick-check.

More information (German)

Integrating smart features in CREE hybrid timber components is a standardised process that begins in the early design stage and continues throughout the prefabrication process. Easy replacement and upgrading capabilities mean the interior configuration and layout can change and evolve during its lifecycle with minimal effort. Various elements with their connections allow for an almost Lego-like simplicity in construction. As a result, the district can adapt to changing uses very easily.

Showcase: Shandong Vocational College, Jinan

The Shandong Vocational College for Urban Construction east of Jinan is a beacon for building efficiency. After two and a half years of construction, the building's 20,000 square metres (> 92% heated) were finalised in 2019. Optimised insulation and airtightness minimise heating and cooling needs to reach a final energy demand of 2.15 kWh/m²a. Other KPIs include the following listed in Table 10.

Central strategies to achieve this high level of energy efficiency include:

- *High-performance external insulation, door and window systems*
- *Avoidance of heat bridges*
- *High-efficiency heat recovery fresh air system*

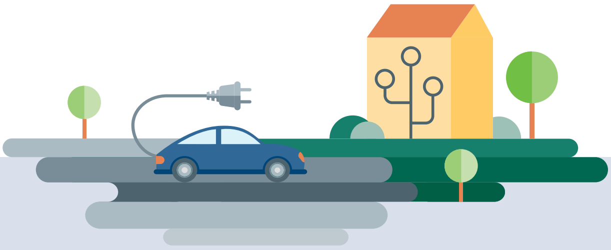
More information

4.4 Synergies between buildings in the district

Three examples are briefly explained to highlight the potential for synergies between buildings in the district if energy and end-use sectors are combined:

1. Use of waste heat within buildings
2. Use of waste heat between buildings
3. Use of excess PV electricity in buildings with large roof areas

Synergies between different zones can already be exploited in buildings themselves. In buildings with a simultaneous heating and cooling requirement, for example, the exhaust air from the zones with cooling requirements can be used to heat the other zones. This is already being implemented in buildings with larger server capacities. Simultaneous heating and cooling requirements can even exist in office buildings with significantly different solar profits between the north and south sides. The thermal compensation of buildings is often limited by the main use of the buildings or by the seasons (simultaneous heating and cooling primarily during transition periods). Extending the perspective to encompass several buildings can lead to identifying potential, especially in districts with different uses. For example, a data centre has a year-round cooling requirement and can release the waste heat to buildings that require heat, such as residential buildings in the winter and swimming pools in the summer.



Importance of prosumers

Changes are occurring in the energy and end-use sectors as well. Electrification is causing a shift from traditional fossil energy carriers, while decentralised renewable energy is making prosuming more economical. This applies to both the heating sector with heat pumps and the mobility sector with increasing demand for e-mobility. Also, prosuming is becoming more and more important as power generation capacity is increasingly decentralised and applied by traditional energy consumers.

Changes in usage include the rising demand for housing in cities and a decrease in CTS areas due to the digitisation of employment (home offices) and consumption (e-commerce) patterns. Some industry sectors are seeing an even larger shift in processes and energy demand type.

Implementation strategies

Based on the described trends and changes in energy demand, there is a need to plan and foresee possible changes in demand types and patterns. General and specific strategies make it possible to incorporate these changes at an early stage:

General strategies:

- A consistent foresight analysis combined with scenarios helps to foresee changes in the district. Individual end users need to be considered consistently.
- A mixture of use types creates both synergies and resilience against a decline and change in demand. Some business sectors are more affected by these change drivers.
- Sector coupling can compensate for structural change in daily use by using overcapacities in one sector in times of scarcity in another, for instance.
- A continual assessment and development of new business models help the district (energy system) react and adapt to structural change.

A selection of specific strategies can be applied:

- ‘What-if’ scenarios to explore long-tail events and rapid change.
- A ‘less is more’ approach to maintain flexibility in further system expansion and avoid lock-ins by reducing technical requirements to a minimum.
- Step-by-step plans to avoid rushed technology decisions and lock-ins.
- The choice of the most flexible technology solution **or** the courageous decision for technology with all consequences.

The prerequisites for the direct use of waste heat are:

- The temperature level of the waste heat
- The power of the waste heat
- An existing infrastructure for the use of waste heat

Buildings in the district can also benefit from synergies in the electricity sector. Different key figures for the characterisation of land use are presented in step 1. Buildings with a large area requirement but lower electricity requirements (e.g. warehouses or logistics centres) have great potential for installing PV systems: the electricity can be used directly in the neighbouring buildings.

It is possible to form factors between different energy forms or requirements (e.g. cooling/heat demand or PV generation/electricity requirement) to evaluate the basic potential for districts at an early stage. The simplest form is determining the annual energy balance and comparing the maximum outputs. However, this assessment does not consider simultaneity between generation and demand, which is crucial for optimal and, therefore, climate-neutral operation. Factors used primarily in research, such as the Diversity Index by Pass, Wetter and Piette (2017) and the Demand Overlap Coefficient according to Wirtz, Kivilip, Remmen and Müller (2020), also consider the temporal occurrence of the respective services providing a more realistic assessment of the potential for exploiting synergies.

Takeaway:

For the planning of district energy systems, the thermal and electricity demand in buildings must be considered integrally from the beginning. This results in several challenges in the future due to both unforeseen and foreseeable trends in demand types and patterns. Solid foresight analysis and subsequent response strategies need to be developed.

Building physics design and architecture affect heating and cooling services. Static or dynamic transfer systems can be chosen to provide air conditioning, resulting in different heating or cooling flow temperatures. These conditions determine the corresponding heating and cooling system.

Generation from energy sources in the districts and energy demand can be balanced if technical requirements such as heat grids and storage systems are integrated. The potential can be identified in early project phases by applying suitable KPIs and facilitate the shift of possible demand patterns with the help of demand-side management (DSM) and storage systems.

Showcase: HafenCity in Hamburg, Germany

A large-scale waste heat project is being developed In Hamburg's emerging district called HafenCity. Upon completion in 2030, this district will be home to 15,000 people and offer employment for 40,000 people. The waste heat is generated by a treatment facility for non-ferrous metals and used by the municipal ESCO in the district. As soon as the district's development was announced, the company seized the opportunity to monetise its waste heat.

Industrial heat in the plant is generated by flash smelters and a chemical copper production subprocess. Sulphur dioxide – a by-product of copper purification – is converted to sulphuric acid in a special boiler lined with acid-resistant bricks, releasing virtually carbon-free heat. This heat is used to heat the water to 90 °C, which is then delivered via a 3.7 km district heating pipeline to the HafenCity East neighbourhood, where it is fed into the municipal heating grid. The pipeline is designed to accommodate Aurubis' entire industrial heat potential of 60 MW. An energy control centre on the pipeline route uses a buffer storage facility to store excess heat, releasing it again as needed to safeguard and even out the highly fluctuating industrial heat.

About half of the reduction in GHG emissions comes from replacing the natural gas used to produce steam on the plant's premises: some of the industrial heat is now used by the plant itself, which would not have been economically viable without the additional heat consumers in HafenCity East. The current heat volume of 160 GWh per year could be increased by another 500 GWh if a large investment were to be made in both the plant and the municipal heating infrastructure. Another benefit of the project is the reduced use of cooling water (12 million m^3 less per year).

More information
(German)


YOGHURT STORE

Step 5: Energy concept II: Characterisation of the energy potential

Following the characterisation of the districts and their corresponding energy demand, the energy supply is the next relevant consideration. In the interest of providing an overview of how the energy supply can be structured, an initial characterisation is made based on data and KPIs (Section 5.1). Then, starting with the status quo, three supply variants are discussed (Section 5.2). Subsequently, the idealised scenarios of fully electric districts and hydrogen districts are presented with a common scheme used to represent generation structures in the interest of describing the transformation of energy systems. Finally, the role of electric and thermal storage technologies is discussed (Section 5.3).

5.1 Characterisation of the energy supply

The greatest challenge in the transformation path for the energy supply of districts is the high dependence on fossil fuels in the current energy supply of buildings. This fact is highlighted in Figure 8, which presents the shares of different energy systems for the supply of space heating and hot water in Germany and North China.

The key to addressing this is to implement energy efficiency measures to reduce energy demand significantly, in addition to a strategy to exploit climate-neutral energy potential. The selected KPIs in Table 11 provide an overview of the configuration and operation of the energy system in the interest of analysing the characteristics of a given energy system.

Type	KPI	Unit
Energy system configuration	Installed capacity	[MW]
	Installed storage capacity	[MWh]
Energy system operation	Imported/ exported energy	[MWh]
	Share of local energy	[%]
	Residual profile[1]	[MWh/h]
	Energy efficiency (by sector)	[%]
	Global warming potential	[kgCO$_2$eq/kWh]

Table 11: KPIs for the energy system configuration of districts

5.2 Different pathways: All-electric and green hydrogen

A uniform scheme is used to represent generation structures when describing the transformation of energy systems. In the following section, three supply variants will be discussed. First, the status quo, which refers to existing districts and cities, is discussed. Then the idealised scenarios of all-electric districts and hydrogen districts

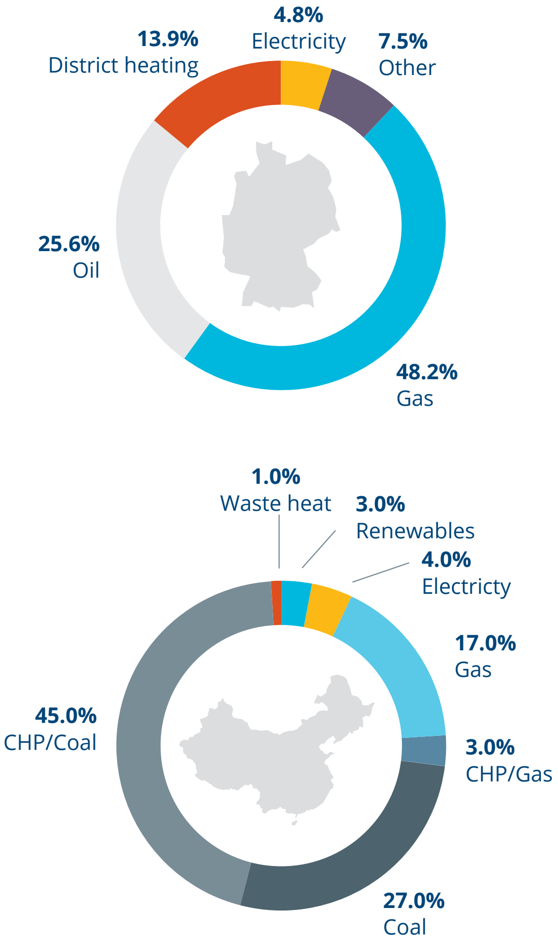


Figure 8: Share of heating systems in Germany and North China (Bundesverband der Energie-und Wasserwirtschaft e.V. (BDEW), 2019; China Heating Society, 2020)

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[1] Difference between energy use and imported or exported energy in MWh/h to characterise the hourly or seasonal dependencies on the higher-level energy systems

are discussed. These scenarios are “idealised” in that they show two possible pathways to future district energy systems, but there will likely be other developments and combinations of both, especially in existing districts.

Figures 9, 10 and 11 show the above-mentioned common scheme and outline further generation structures. They show the various energy demands for each sector (heating, cooling, electricity and gas) on the right. As a simplification, different voltage levels or different temperature levels are not shown. On the left side, a vertical grey dashed line marks the district boundary. Generation capacities to the left of this line correspond to an import into the balance boundary (negative energy balance), and to the right, they correspond to a local generation or conversion. Main imports into districts are electricity, fossil fuels (e.g. natural gas for Germany) and district heating from large power plants (e.g. coal power plants in Germany and China). The challenges in defining district boundaries were already discussed in step 2. The definition used follows the “Geographic Plus” approach.

The horizontal lines indicate the respective energy supply, representing both a centralised (e.g. electricity grid) and a decentralised supply option (e.g. direct use of PV electricity). Several producers can cover the energy demand of the different sectors. In the current situation (see Figure 9), a large part of the heat is provided by fossil fuel-based generators. Both oil and gas must be imported into the district. Heat pumps provide a growing share of the heat supply, and more buildings and districts are equipped with PV systems for local electricity generation. Electrically driven compression chillers provide most of the cooling.

Three different pathways are compared: a status quo scenario based on decentral gas boilers, an all-electric scenario using solely electricity-based components and the hydrogen scenario, which replaces the natural gas grid with a hydrogen grid.

The status quo

In the status quo scenario, heating is mostly provided by decentral gas boilers with only a few electric heat pumps and some oil boilers, whereas cooling is provided by electric chillers. Gas and electricity are mainly imported from central infrastructures, and local PV only plays a marginal role.

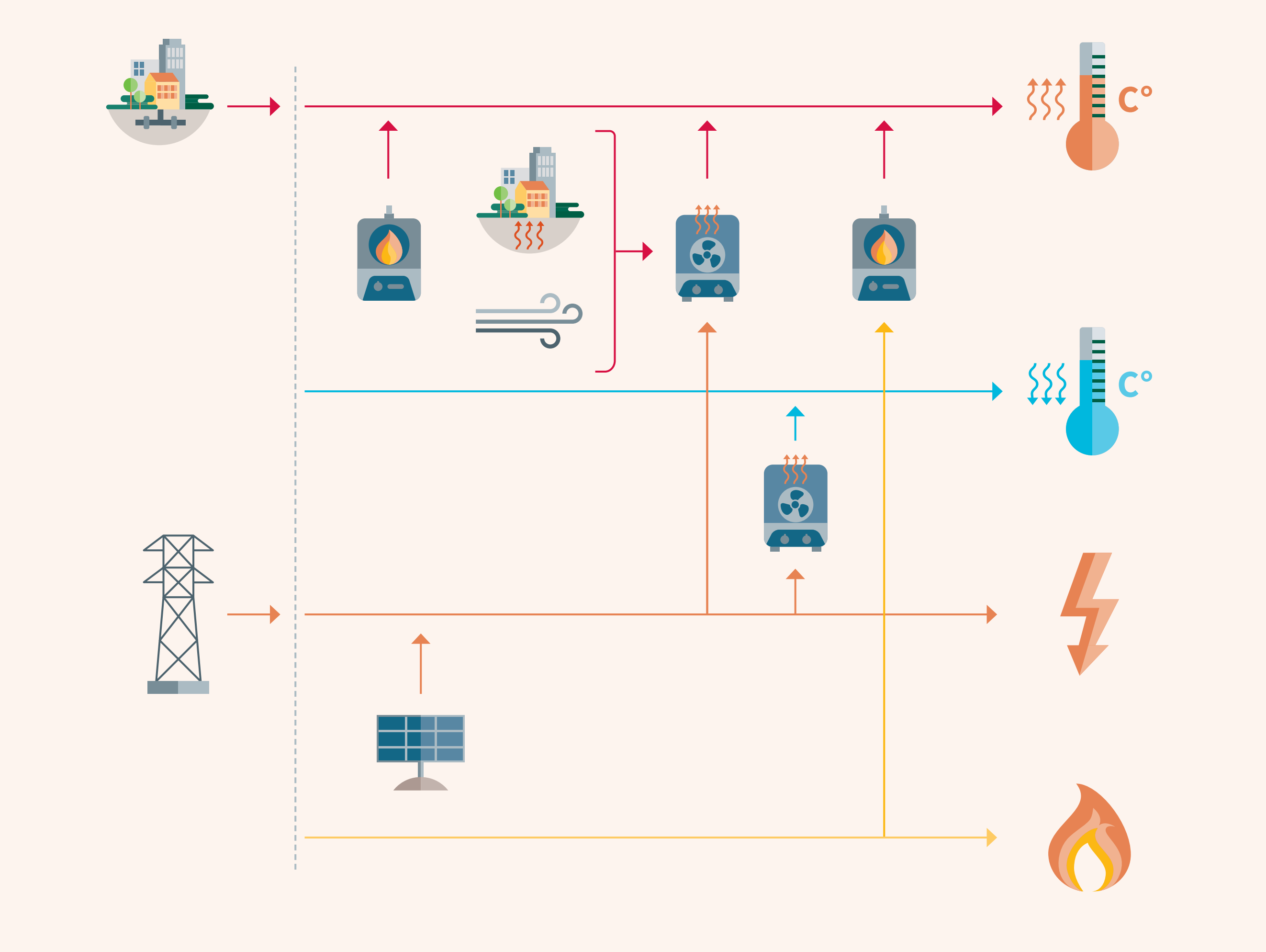

Figure 9: Energy system configuration of districts in the current situation

The status quo scenario is characterised by the following aspects regarding energy import, the use of local energy sources and residual load:

Energy import: A large part of the energy used in the district is currently imported and based on fossil fuels. In addition to electricity, gas (Germany) or other fossil fuels (China) are used to cover heating requirements in the district. The direct import of heat by district heating is also an option.

Use of local energy sources: PV systems are increasingly used as local energy sources in existing districts. The growing installation of heat pumps (Germany) increases the use of local energy sources (environmental heat) in the heating sector.

Residual load and flexibility potential: In existing districts, the energy balance is negative in almost all hours of the year as only a few decentralised generators and little local energy potential are utilised.

The all-electric scenario

For the all-electric scenario, the holistic electrification of all sectors is assumed. Generation units for heat from fossil fuels such as gas and oil are replaced by electric generators (essentially heat pumps). The transport sector is electrified, resulting in additional energy demand in and near buildings. The expansion of local energy converters will cover part of the increased electricity demand. Figure 10 shows the structure of an all-electric district energy system.

Typically, the entire gas sector is omitted, especially for gas applications such as high-temperature applications in industry, which should be examined and considered in the district's planning. In an all-electric district, the producer structure for heat becomes more homogeneous – mainly heat pumps, which can be supplemented by electric boilers (not shown in the structure). Although there is a clear trend towards heat pumps for energy conversion, the source of heat pumps in future districts will be more heterogeneous. All existing local heat sources must be fully exploited. In addition to the air and

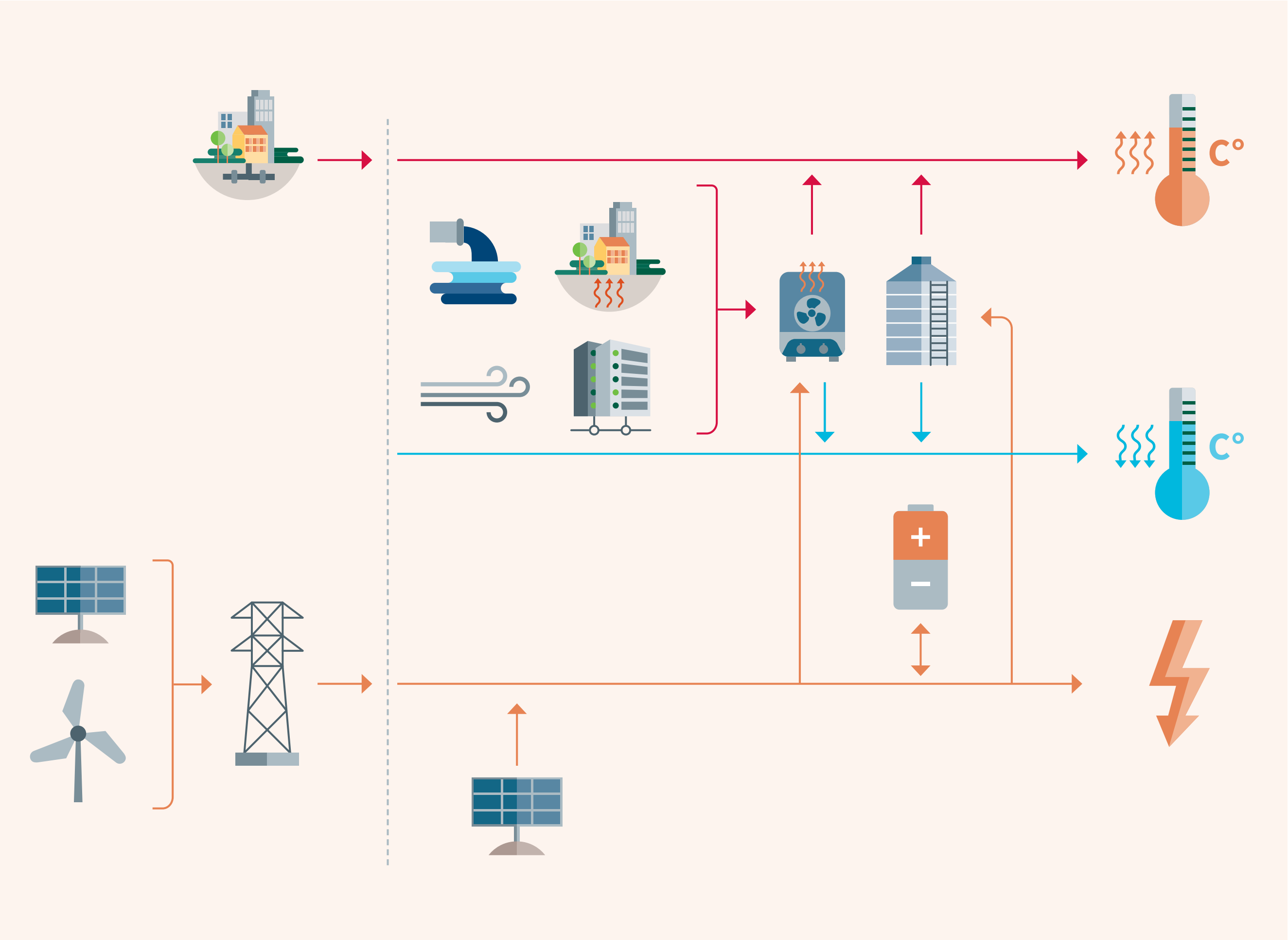

Figure 10: Energy system configuration for a district's energy system in the all-electric scenario

geothermal energy sources already used today, this also includes using heat from wastewater or heat recovery from data centres. Compression chillers are the main source for cooling, but available heat sources in winter can be used for cooling in summer (especially geothermal energy and wastewater).

A larger part is generated in the district itself, not only for thermal energy sources but also for electrical energy conversion, with PV playing a major role. In Germany, there are high regulatory requirements for wind energy (e.g. distance regulations), which means that the direct use of local wind energy depends on the district's density and the local conditions (e.g. inner city or rural structure).

It is also possible to import electricity and heat via district heating networks in an all-electric district; however, these imports must also come from renewable energies (e.g. large-scale heat pumps for heat and wind, solar and hydro energy for electricity). The importance of proper balancing is particularly evident here. In an all-electric district, no local emissions are emitted, but climate-neutral operation can only occur if the imports into the district are also climate-neutral. Thermal and electrical storage, which will be discussed in more detail below, complement the system.

Energy import: Mainly renewable electricity is imported into the district. There is also the possibility of importing district heating from renewable sources. Fossil fuels are not imported directly (e.g. petrol at petrol stations) or indirectly (electricity).

Use of local energy sources: PV systems are the major local energy source. All possible areas should be equipped to satisfy the increasing electricity demand. Among others, the coverage depends on the density (FAR) and the types of energy demand. Also, local resources for heating (as sources for heat pumps) and cooling are exploited. In addition to air and geothermal, wastewater and low-temperature heat recovery will become more important.

Residual load and flexibility potential: For all-electric districts, the residual load is neutral or positive in summer and on sunny days in the spring, autumn or even winter due to high installed PV capacities. Depending on the storage system used, the daily residual profile might vary between day (positive) and night (negative). There is a high fluctuation in the residual load considering the different seasons (winter more negative, summer more positive).

The hydrogen scenario

Hydrogen is currently discussed as an essential component of the energy transition. For this reason, a district energy supply relying solely on hydrogen is further analysed. In this scenario, natural gas is completely replaced by hydrogen. Internal combustion vehicles are also replaced by hydrogen-powered vehicles. The resulting energy system diagram is shown in Figure 11.

Compared to the all-electric transformation pathway, it should be noted that the gas sector plays a decisive role, as it does in the status quo. The main difference to the status quo is the switch from natural gas to hydrogen. The transport sector is not electrified but also uses hydrogen as an energy source. The hydrogen is produced exclusively from renewable sources by means of electrolysis (green hydrogen). Electricity is either generated locally (mainly PV) or imported, as is the case in the status quo and the all-electric scenario. One advantage of imported hydrogen is its transportability via local and regional gas grids, but also by using ships for long-distance imports. Theoretically, this means that the hydrogen can be produced in energy-rich regions and transported to the place of use.

In contrast to the all-electric district, the generation structure in the heat sector is more heterogeneous. Cogeneration (either CHP or fuel cell) or gas boilers can be used to cover the heat demand. All technologies use hydrogen as an energy source. The use of waste heat from electrolysis can also be an important option. Heat storage is used less in this district configuration as the efficiency (see example below) and associated heat generation costs are higher than in the all-electric district. Importing district heat is still a valid option if it is generated from renewable sources. High-temperature applications do not place any special demands on the planning in a hydrogen district, making this scenario particularly relevant for high-temperature industry applications.

The cooling supply can be supplemented with absorption chillers. However, this only makes sense if the necessary heat comes from processes such as electrolysis or regeneration through CHP plants. Heat-led operation of cogeneration to supply the absorption chillers is not economical in the hydrogen scenario, resulting in electricity-led operation.

The hydrogen district offers the possibility to set up local, decentralised electrolysers and thus to produce and store hydrogen with local surplus electricity in the district energy system (e.g. in the summer). This reduces electricity exports in the summer and can help to reduce

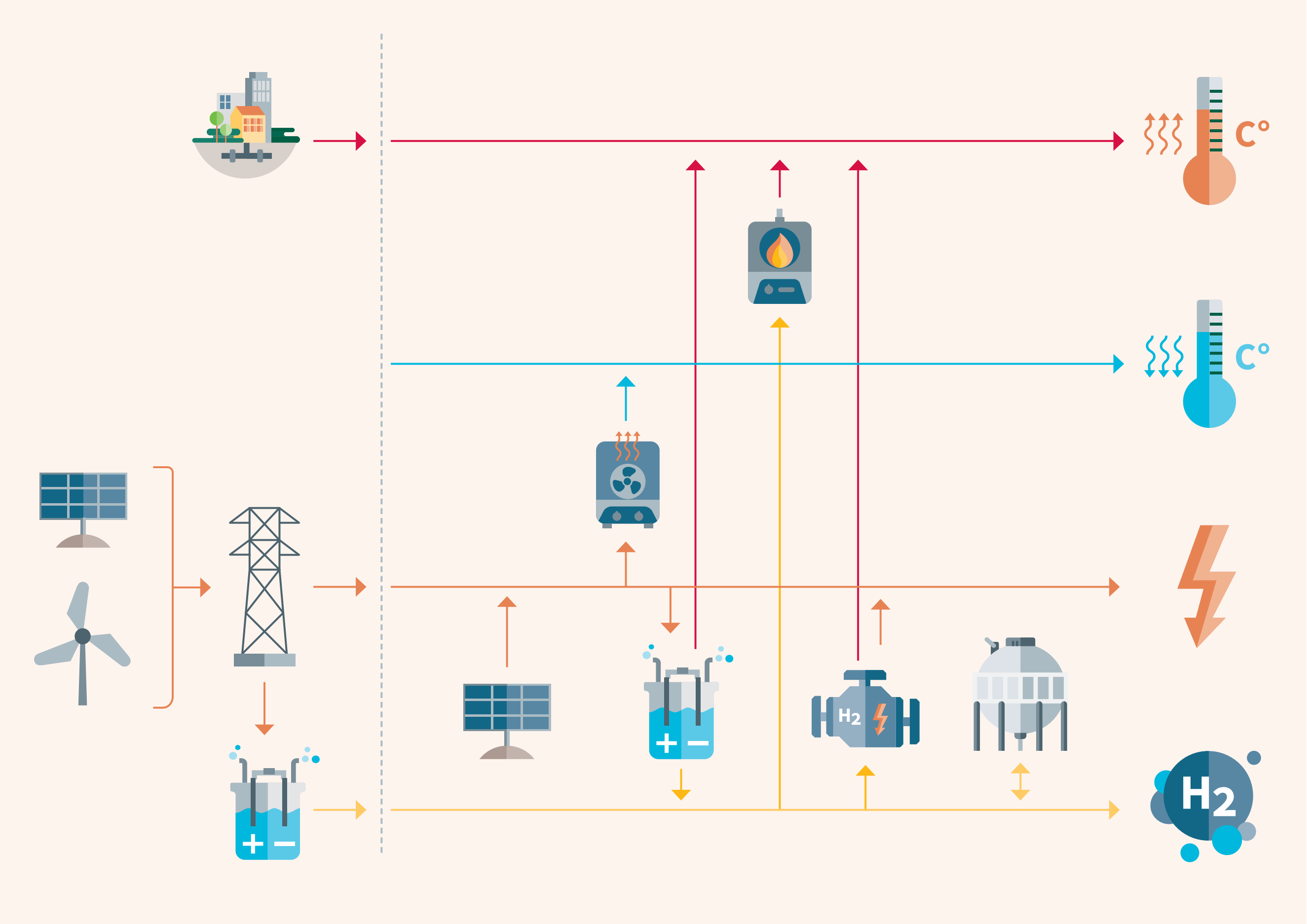

Figure 11: Energy system configuration for a district's energy system in the hydrogen scenario

the daily and even seasonal residual load. Possible hydrogen storage systems include pressurised storage, as well as pore and cavern storage.

Energy import: Renewable electricity and green hydrogen are imported in large quantities into the district. There is also the possibility of importing district heating from renewable sources. Fossil fuels are not imported directly (e.g. petrol at petrol stations) or indirectly (electricity).

Use of local energy sources: PV systems are the major local energy source. All possible areas should be equipped to satisfy the increasing electricity demand. Among others, the coverage depends on the density (FAR) and the energy use. Also, local resources for cooling are exploited (e.g. geothermal and wastewater). Waste heat from electrolysis and cogeneration plants is also considered a local resource.

Electric residual load and flexibility potential: For hydrogen districts, the residual electricity load is both negative and positive depending on the weather conditions and season. The daily residual profile might vary between day (positive) and night (negative). The residual load fluctuates greatly depending on the season (winter more negative, summer more positive). Storage capacities (hydrogen storage) can be used to decrease the positive residual load in the summer, as hydrogen storage systems can serve as seasonal storage. The residual load for hydrogen itself will likely be negative as locally produced hydrogen will be used in cogeneration plants for heating or transportation.

Comparison between the all-electric and hydrogen scenarios

Both pathways (all-electric and hydrogen) have advantages and disadvantages that must be considered. The decision favouring one of the two pathways or a combination of both must be made individually for each district. The advantages of using hydrogen as the main energy carrier are that it can be transported over long distances, stored in large quantities, and used flexibly as a fuel for high-temperature applications. On the other hand, there are particularly high conversion losses in generation and the associated higher surplus outputs of renewable energies. Not all the technologies necessary for a hydrogen district are available on an industrial scale (e.g. boiler and storage or transport networks). In this regard, there are significant advantages to the all-electric district, as all the technologies are available on an industrial scale and are market-ready. Depending on the sector and the application, the all-electric district is also more efficient.

In Figure 12, the efficiency of the two pathways is compared based on the heating sector. The diagram shows the conversion of one unit (100%) of renewable electricity to heat. The electricity can be converted to heat using a heat pump and the available environmental heat (e.g. air or geothermal). The heat pump's coefficient of performance (COP) indicates how much environmental heat can be added to the electricity used for heat pump operation. Commercially available COPs range between 3 and 6. The COP depends greatly on the temperature difference between the energy source (e.g. geothermal) and sink (building energy demand), which is why there are only limited applications suitable for high-temperature applications. On the hydrogen pathway, the electricity is first converted to hydrogen via electrolysis (around 60–80% efficiency). That hydrogen is then burnt in a boiler with an efficiency between 90% and 98% to generate heat. This heat can have almost any temperature level. The diagram illustrates the higher efficiencies in the heating sector of the all-electric district but also shows the application limits.

Efficiency gains in the all-electric district are also confirmed in other sectors (e.g. transport or power sector). Based on the general energy conversion chains of the two districts shown in Figure 12, it becomes clear that both pathways are based on electrification with an additional conversion step for the hydrogen district. If the boundary conditions are suitable (e.g. temperature in the heat sector or high simultaneity), the all-electric pathway is preferable. The hydrogen pathway is of interest for industrial applications. Its advantages include long-term storage and transportation possibilities.

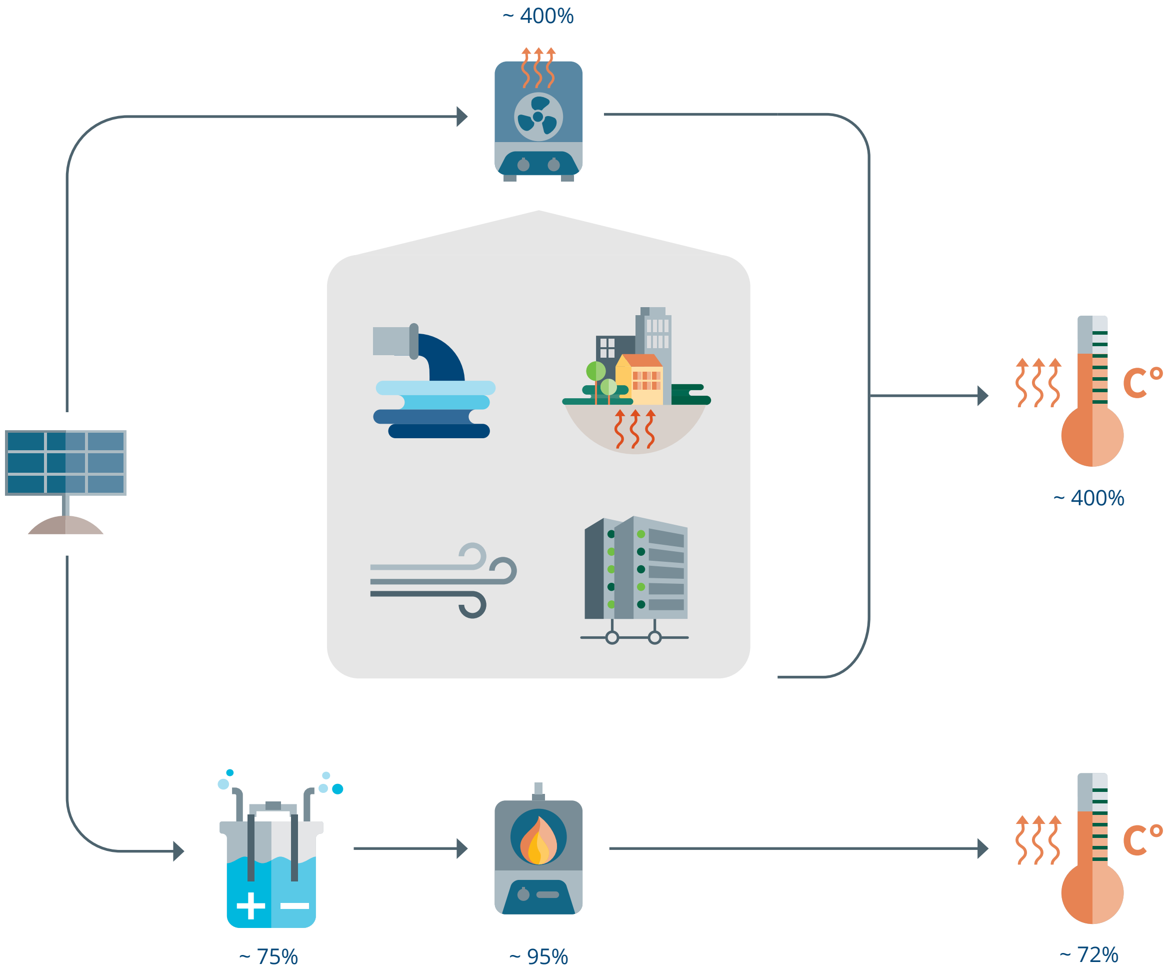

Figure 12: Comparison of efficiencies of all-electric and hydrogen districts for the heating sector

Showcase: Weststadt Esslingen and Shamrockpark, Germany

Both scenarios are already established in different districts. Weststadt Esslingen serves as an example for hydrogen, whereas Shamrockpark represents the all-electric pathway.

In Weststadt Esslingen, a new district with an energy system based on green hydrogen is being constructed. In total, 550 apartments, a high-rise office block and a new university building for about 1,800 students have been developed since 2016.

Rooftop PV is used to generate renewable electricity, which is used directly to cover electricity demand. Overproduction is used in the district's electricity network to support heating with a P2G and a P2H system, both feeding (waste) heat into the heat grid. The hydrogen produced is used for both power and heat in an engine-based hydrogen CHP. This system proved to be more economical than fuel cells. The primary goal is to use hydrogen on-site. Surplus hydrogen is then either fed into the natural gas grid or sold to industry outside the district since no large seasonal storage is possible due to limited space. Another planned use for hydrogen lies in the mobility sector, with a hydrogen fuel station for vehicles in planning. Additional electricity storage facilities serve to compensate for short-term deviations between renewable generation and electricity demand in the district.

It is estimated that the 1 MWel electrolyser will produce about 2,800 MWh or 85 tonnes of hydrogen per year. The electrolyser itself also produces about 600 MWh of waste heat per year. Using this waste heat from the electrolysis process increases efficiency from around 55–60% to 80–85%. Furthermore, the energy centre is equipped with a heat pump (200 kW_{th}), a bivalent cogeneration unit (natural gas 300 kW_{th}, H_2 138 kWth) and a gas peak load boiler for the full year-round heat supply. In case of electrolyser failure, the CHP can also work with a hydrogen-biogas mixture or pure biogas to ensure a steady and climate-neutral energy supply. Barring such a failure, the gas peak load boiler should only be used during the winter or during maintenance works on the CHP. Moreover, a combined heat, power and cooling system is planned for the campus and the office block, with an absorption chiller converting the waste heat from the CHP system into cooling energy.

This complex configuration of the energy system makes it possible to maximise the local share of the energy supply. Hydrogen production also compensates for over- or under-supply and prevents grid congestion.

More information

In contrast, Shamrockpark on the former site of a coal company's headquarters in the city of Herne exemplifies the all-electric pathway in a mix of newly built and existing buildings. Shamrockpark is part of "TransUrban.NRW", a project funded by the Federal Ministry for Economic Affairs and Energy (BMWi) until 2025 as a "laboratory for the energy transition" ("Reallabor der Energiewende").

Advantages of renewable electricity

Both energy systems with high use of climate-neutral gas and all-electric district energy systems rely on renewable electricity generation for their usage. Both district types require a significant expansion in renewable power capacity. Climate-neutral gas and, most notably, green hydrogen are necessary for industrial processes that cannot be electrified.

Choosing renewable electricity as the basis for climate-neutral districts comes with many advantages. First, the shift from fossil fuels and, consequently, the reduction in emissions are accelerated as generating electricity from renewable sources is cheaper than fossil alternatives. In the gas sector, high hydrogen prices mean fossil fuels keep their economic advantage, which hinders the shift to a climate-neutral energy provision if no subsidy scheme is established. Second, more efficient electric processes, which use less energy, compensate for the scarcity of energy in urban or industrial areas, for instance, making it easier to cover these areas locally. With space heating, the use of environmental and geothermal heat even adds to the efficiency by exploiting more local potential. Third, thermal storage systems can be operated flexibly between the heat and electricity sectors while also including environmental heat. The parallel operation of gas and thermal storage systems might decrease cost efficiency, leading to the district energy system performing more poorly.

Technically, the energy infrastructure is characterised by a heating and cooling grid and the maximisation of local electricity use in e-mobility, heat pumps, CHPs and charging stations. Specifically, the ectogrid™, a 5th generation heat network, covers both heating and cooling needs simultaneously with only two pipes. The ectogrid™ works like a thermal battery: The buildings connected to the ectogrid™ work as a prosumer by using heat pumps and/or heat exchangers to provide heating and cooling. In Shamrockpark, the buildings use a heat pump for heating and a heat exchanger for passive cooling. The buildings add or withdraw heat energy from the grid, depending on their heating or cooling demand. All the buildings balance each other out, which is further facilitated by commercial cooling demand even in the winter. Thus, the ectogrid™ effectively reuses all available thermal energy and requires a significantly lower outside energy input, particularly in the spring and autumn when the heating and cooling demand are approximately the same. An important feature is the technical capacity to use low-temperature waste heat from an adjacent chemical plant as a waste heat source. The system's 5 MW heating capacity and 4 MW cooling capacity are expected to cover an annual heat demand of 8 GWh.

Since every building can take or give energy to the grid to fulfil its heating or cooling demand, there is no predetermined flow direction in the pipes. If the demand for heat dominates, cooled water is pushed towards the cold pipes, moving towards the thermal storage tank. If the demand for cold is higher, the water in the cold pipe moves towards the buildings. Depending on the specific requirements of the district, the network can be operated at temperatures that can range between approximately 0 and 30 °C. For the application in Shamrockpark, the temperatures are fixed at 12 °C in the cold line and 22 °C in the warm line, with a temperature difference between them of 10 K. As the grid operates at temperatures similar to the surrounding earth, distribution losses are very limited. Distributed pumps in each building control the flow of the transport medium (either water or water with an added anti-freeze component to avoid frost damage) to meet the required demand and maintain the desired grid temperatures. A thermal storage tank connected to the grid controls daily variations in heating and cooling demand.

More information
(German)

5.3 The role of electric and thermal storage technologies

As a result of the fluctuating nature of renewable energies, the use of storage systems is crucial for all sectors and all pathways. Figure 13 illustrates the average amount of solar electricity generated in a location in Germany compared to the average residential heat demand relative to the maximum and demand month.

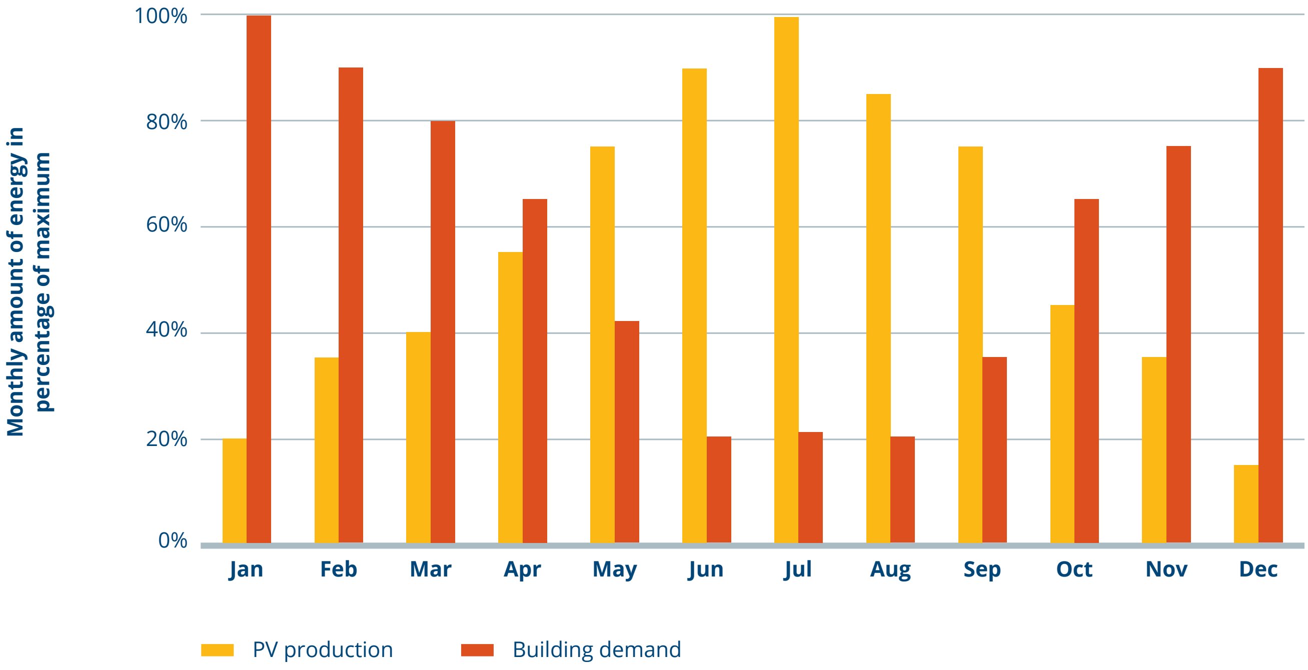

Figure 13: Comparison of relative monthly heating demand and potential PV electricity generation – energy storage is necessary to overcome the imbalance

It becomes clear that there is under- and overproduction of electricity in both the short term and the long term (seasonal). Storage capacities must be kept available in all district configurations to balance these fluctuations.

These storage capacities can be subdivided, such as according to their physical mode of operation:

- Thermal
- Chemical
- Mechanical

Thermal storage can be further subdivided into sensitive or latent storage. Latent storage also uses the phase change of a material for storage (e.g. solid-liquid water). Typical examples of sensitive storage are hot water buffer storage or high-temperature storage with metallic or other solid storage media, such as ceramics or (volcanic) rocks. The most common latent storage in districts is ice storage.

Chemical storage is further subdivided into electrochemical and material storage. Electrochemical storage units include batteries that store electricity directly through a chemical reaction. Hydrogen storage is an example of material storage; material storage can be in liquid or gaseous form.

Mechanical storage (e.g. pumped storage power plants) is not relevant for districts.

All-electric districts mainly use thermal storage and electric battery storage systems, see Figure 10. The thermal storage units can have different temperature levels. The most common application is sensitive storage technologies in the temperature range of the respective usage temperatures. However, high-temperature storage (up to 500 °C) as a coupling technology to the electricity sector and ice storage in the case of low local energy sources are also possible. High-temperature thermal storage can, for example, help incorporate renewable energies and decarbonise industry processes, e.g. by providing thermal energy and/or process steam.

Hydrogen districts mainly use hydrogen storage but also electric battery storage systems, see Figure 11. The hydrogen storage units are pressurised storage systems for short-term use or even cavern storage systems for yearly balance. It is not likely that thermal storage be applied on a large scale.

The design of the storage systems installed in the district depends on several factors. Storage systems must be adapted to the demand behaviour as well as to the generation capacities. Since large storage facilities are expensive, an ideal storage design does not necessarily mean that every energy flow in the district (short-term and seasonal) can be balanced. The KPIs listed in Table 12 are relevant for designing a district's energy system storage system.

Type	KPI	Unit
Storage size	Maximum storage capacity	[MWh]
	Power (charge/discharge)	[MW]
	Storage volume	[m³]
	Energy density	[MWh/m³]
Storage operation & flexibility	Storage efficiency	[%]
	State of charge	[0-100%]
	Stand-by losses	[MW]
	Charging/discharging characteristic	[ ]
	Number of charging cycles	[ ]
	Operation temperatures	[K]

Table 12: KPIs for storage systems

In addition to the special importance of storage, the transformation of infrastructures is also crucial for all sectors and transformation pathways. Here, the requirements may differ depending on the chosen technology.

For the all-electric approach, the electricity infrastructures, in particular, must be designed so that they can cover the higher electricity demand and the higher power on the one hand and an increase in decentralised feed-ins (prosumers) on the other. The use of many heat pumps requires large amounts of ambient heat or waste heat. These are often locally separated from the consumer so that in the all-electric scenario, district heating and cooling networks play a greater role even at very low temperature levels. A gas grid infrastructure is no longer needed in an all-electric district, saving additional operational costs.

In contrast, the gas grid infrastructure is crucial for hydrogen districts. The existing infrastructure must be upgraded to be able to transport hydrogen. Like the all-electric district, the electricity grids must also be designed for higher power and more prosumers. Particularly in the case of widespread regeneration with cogeneration units, the importance of heating grids, which can also be operated at higher temperature levels, is also growing.

The decision for or against an energy system must always be made in consideration of the local conditions. As further specified in step 6, both supply variants have advantages and disadvantages. In particular, the high electricity demands in winter due to many heat pumps can be ideally combined with electricity production in CHP units with hydrogen.

Takeaway:

The decision for or against a specific energy system configuration must always be made considering the local conditions. As further specified in step 6, both supply variants have advantages and disadvantages. In particular, the high electricity demands in winter due to heat pumps can be addressed by using hydrogen to produce electricity in CHP units.

Storage plays a crucial role as it enables the integration of high shares of local renewable energies. Also, the district can ensure a more economical and efficient operation mode by pooling various stakeholders' generation and demand, leading to a better optimum across all stakeholders and the integration of heat storage types, for instance, which are uneconomical for individual stakeholders.

Showcase: Electro-Thermal Energy Storage (ETES) in Esbjerg, Denmark

The Danish port city of Esbjerg is an example of the application of ETES to achieve climate neutrality in the city's district heating system. Formerly home to a hard coal power plant, the city is switching its heat source from the waste heat of a coal power plant to environmental heat from seawater.

After the closure, scheduled for 2023, the former district heat production from the coal power plant will be switched to renewable sources, namely renewable electricity, environmental heat from the sea, and a biomass plant. The project aims to decarbonise the city's heat demand to achieve the municipal climate neutrality goal set for 2030. A key player is the municipal ESCO, which operates the city's district heating grid. The ideal location for the system based on electro-thermal energy storage was at the former power plant site and to use the area and the existing infrastructure, which includes both the facilities to inject the heat into the grid as well as the former cooling installations for the power plant.

The system comprises a 50 MW_{th} *heat pump and a 60* MW_{th} *biomass boiler plant fired with woodchips in times of high demand and technical revisions.*

ETES relies on the Carnot battery with the following characteristics:

1. *Electricity is used in a heat pump to increase the temperature of a medium*

2. *The heat is stored in a medium with a high thermal capacity*

3. *The heat is used in a heat grid*

Additionally, the system can be extended by storage systems with different temperature levels, which can help provide industrial heat, space heating, warm water heating, and cooling. If the size and temperature level of the heat storage allows, the heat can be reconverted to electricity in a turbine.

More information

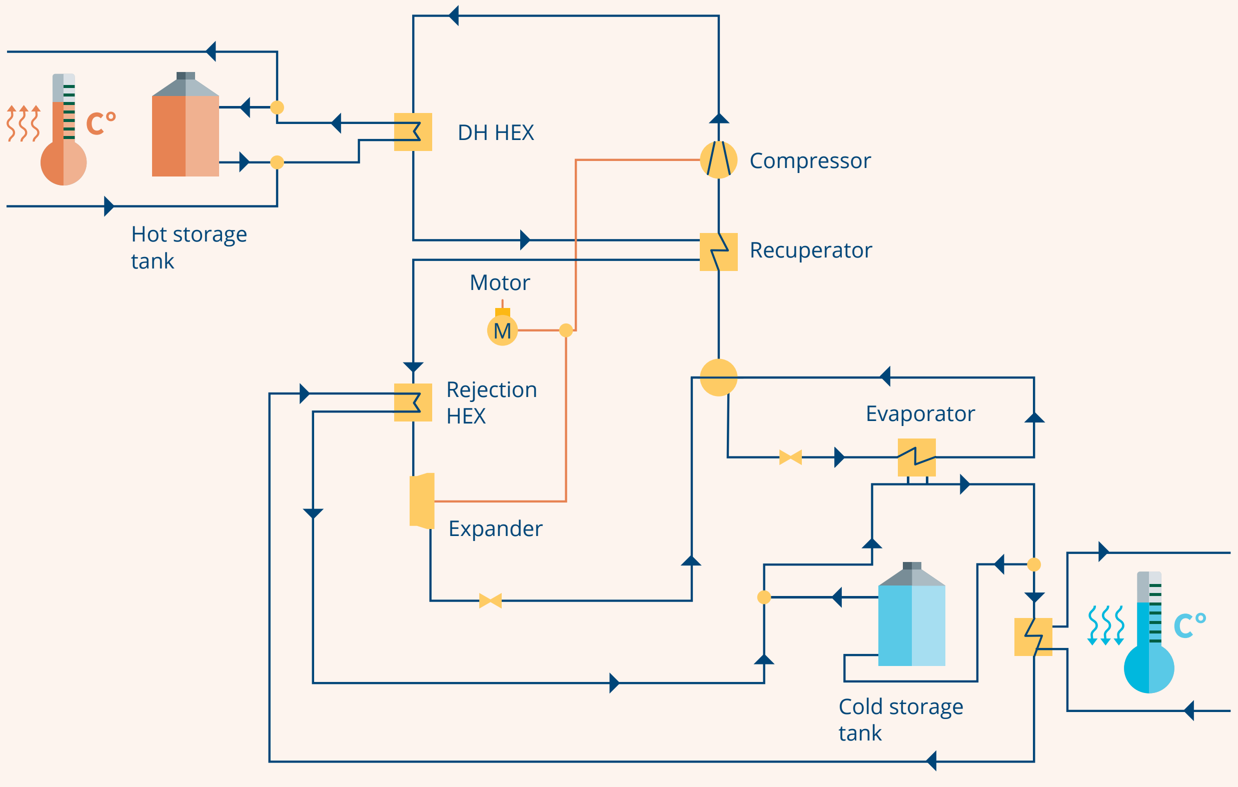

Figure 14: Schematic circuit diagram of ETES

Step 6: Energy Concept III: Technical configurations and scenario planning

To date, energy management systems or building control are only marginally used. Fossil boilers are often equipped with timers that activate the burner and circulation pump at a certain time and switch them off again later. However, the timer does not consider the conditions in the room, the availability of renewable energies or the price difference between different energy carriers. These variables should be considered as doing so makes it possible to optimise the energy system across different energy sectors while minimising costs and emissions. Therefore, an important aspect when planning district energy systems is the control strategy for the various technical components. This aspect will be further described in this chapter, which focuses on step 6 of the roadmap. Section 6.1 shows possible objectives in a district control system and discusses the necessary infrastructures. Step 6 concludes with an example of different energy system scenarios in a fictional district outlined in Section 6.2.

6.1 Setup of district energy management systems

For the consistent control of a district energy system, the following steps need to be followed:

1. Definition of objectives, i.e. fulfilment of given KPIs
2. Methods and strategies on how to fulfil the KPIs
3. Hardware and software infrastructure, which is the prerequisite for active control
4. Implementation of the defined strategy

High shares of renewable energy, which are always the case in climate-neutral districts, result in fluctuating energy supply. These fluctuations need to be managed by effective demand-side management, sector coupling and storage management. The operation of such a management system is subject to different objectives. As an example, the following objectives can be derived using KPIs from the previous steps (not weighted according to importance in this list):

- Reduce/avoid CO_2 emissions (see Table 5 & Table 11)
- Reduce costs (see Table 5)
- Comply with legal requirements (see Table 5)
- Ensure security of supply (see Table 8)
- Avoid peak loads (see Table 11)
- Increase share of local renewable energies (see Table 11)

This list shows that there are higher requirements for operating future energy systems, which leads to conflicting objectives, resulting in the so-called Pareto distribution. KPIs for total project costs and CO_2 emissions are plotted on the axes. In this case, both the CO_2 emissions and total project costs of an energy system are to be reduced. The red dots mark possible solution options (e.g. different control strategies). As is typical of a Pareto distribution, small changes in one KPI at each end significantly impact the other KPI. Thus, significant CO_2 savings can be achieved with little additional cost at the very left, whereas additional CO_2 savings approaching the CO_2 optimum on the far right result in high project costs.

In practice, different methods and strategies are used to achieve the defined objectives. However, often only one or two KPIs are defined as the optimisation objectives. Many of the KPIs are not part of the optimisation but work as constraints (e.g. security of supply must always be assured).

Sector coupling in districts

The optimisation objectives for a district's energy system are key and need to be defined beforehand. In most cases, this objective is cost optimisation, but it can also integrate legal requirements such as emissions in a certain time and area. The objectives are limited by various boundary conditions based on the physical structure, technical requirements, etc. The optimisation objectives are chosen differently depending on the operator, i.e. if the management system is operated by a municipal ESCO, a heat grid operator, a large industry, etc. To achieve an optimum for more stakeholders, an aggregator needs to be found to optimise across multiple energy and end-use sectors. This helps to unleash the synergies and opportunities of sector coupling in the district.

Different strategies are possible to achieve objectives and optimise the operation of district energy systems. Storage units are of particular importance in future energy systems. With the help of optimised control, storage units can uncouple energy generation and energy demand. Energy systems can integrate thermal, electrical, or chemical (hydrogen) storage systems, which can be charged and discharged in a controlled way.

In addition to storage, the control of energy demand is a possible strategy for optimising the system. The goal of demand-side management (DSM) is to promote energy demand at times with a high proportion of renewable energy and to avoid energy demand at times with a low share of renewable energy. That is why measuring and control points, which are managed by the district energy management system, need to be implemented more broadly.

Figure 15 shows the instantaneous energy and flexible energy demand using storage systems or DSM. This figure makes it possible to derive three essential functions for an actively controlled energy system.

1. Peak shaving: The goal is to reduce peak loads. The advantage of reducing peak loads in energy demand is that the energy system (especially peak load systems) does not have to be designed as large as if there were no peak shaving strategies. Peak shaving saves CAPEX costs. In addition, fossil or inefficient energy systems are often used to cover peak demand. With peak shaving (energy demand), the storage is loaded in times of low load and/or high share of renewable energies. At times of higher load (e. g. peak load), the previously charged storage is discharged, and peak load is reduced (DSM).
2. Valley filling: The goal of valley filling is to have a steady energy demand, avoiding energy demand and generation fluctuations. Frequent switching between different load conditions usually means efficiency losses in power generation. Rapid switching between off-peak and on-peak loads is also a challenge. With valley filling, larger fluctuations in energy demand are avoided by charging and discharging storage or controlled by DSM.
3. Load shifting: The goal is to shift loads to an earlier or later point in time. Due to the lack of simultaneity, it may be necessary to separate energy demand from energy generation. This phase shift of loads is also called load shifting and can be achieved by charging and discharging storage units.

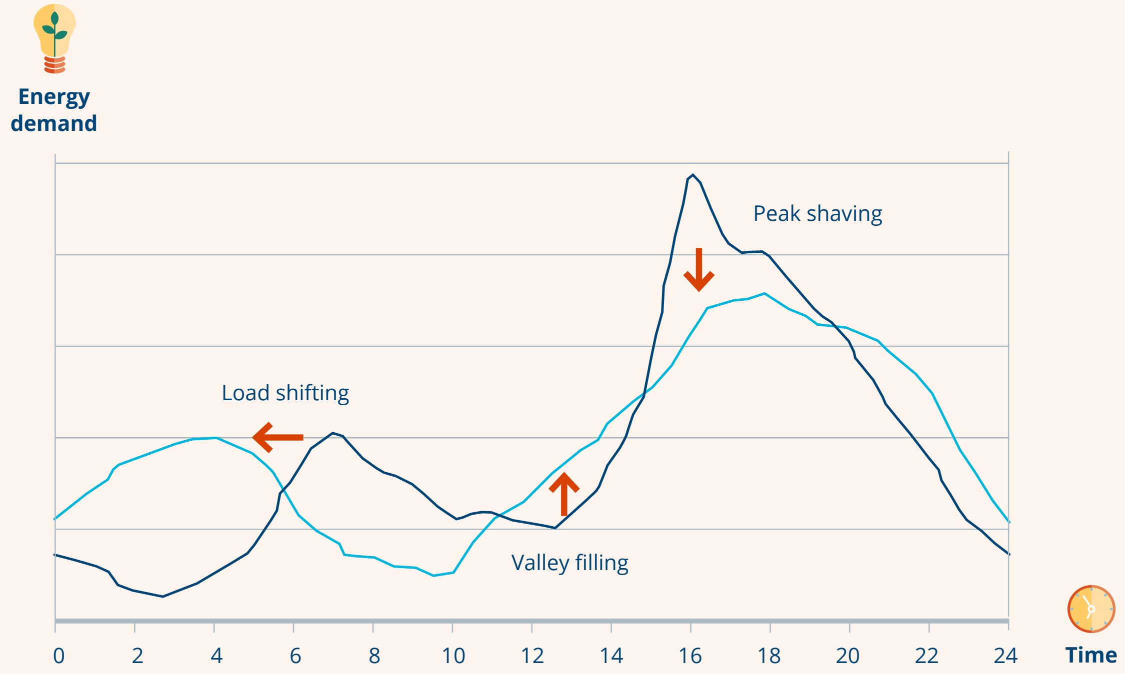

Figure 15: Standard DSM operations

Once the objectives and possible strategies for achieving the objectives have been defined, the final step for implementation is a comprehensive hardware and software infrastructure. Figure 16 shows possible components for a District Energy Management System.

Like a building automation system, a control system for a district energy system also consists of a field, automation and management layer. The field layer comprises buildings, energy sources, energy supplies and other parts of the energy system (e.g. e-mobility). The sensors and actuators of the system are located in the field layer. Depending on the building/part of the energy systems, the number of sensors and (digital) controllable actuators can vary and thus represent a heterogeneous system. The heterogeneity continues at the automation layer. New residential buildings and, increasingly, existing residential buildings are being equipped with smart home applications, such as remote-controllable thermostats, by the users themselves. For non-residential buildings, the use of building automation systems is widespread in both existing and new buildings. The automation layer in Figure 17 represents smart home applications and building automation systems. Local controls are also implemented. Depending on the application, these controls already pursue local optimisations or only ensure the fulfilment of constraints. The management layer brings all the information from all the sensors and actuators in

Energy control in districts

To this day, the centralised control in the electricity sector in Germany leaves little room for local optimisation. As a result, existing district energy systems focus more on the heating sector. Here, optimisation can already help reduce system and energy costs. In the future, optimisation can expand from the heating to the electricity sector. Furthermore, it is important to ensure the system's modularity by integrating different technical installations from various manufacturers. In case of public acceptance needs in the integration of end users, for instance, the accessibility of stakeholders is crucial to increase awareness and subsequently participation. Also, this can help to unleash innovation by integrating new stakeholders and possible concepts and business models.

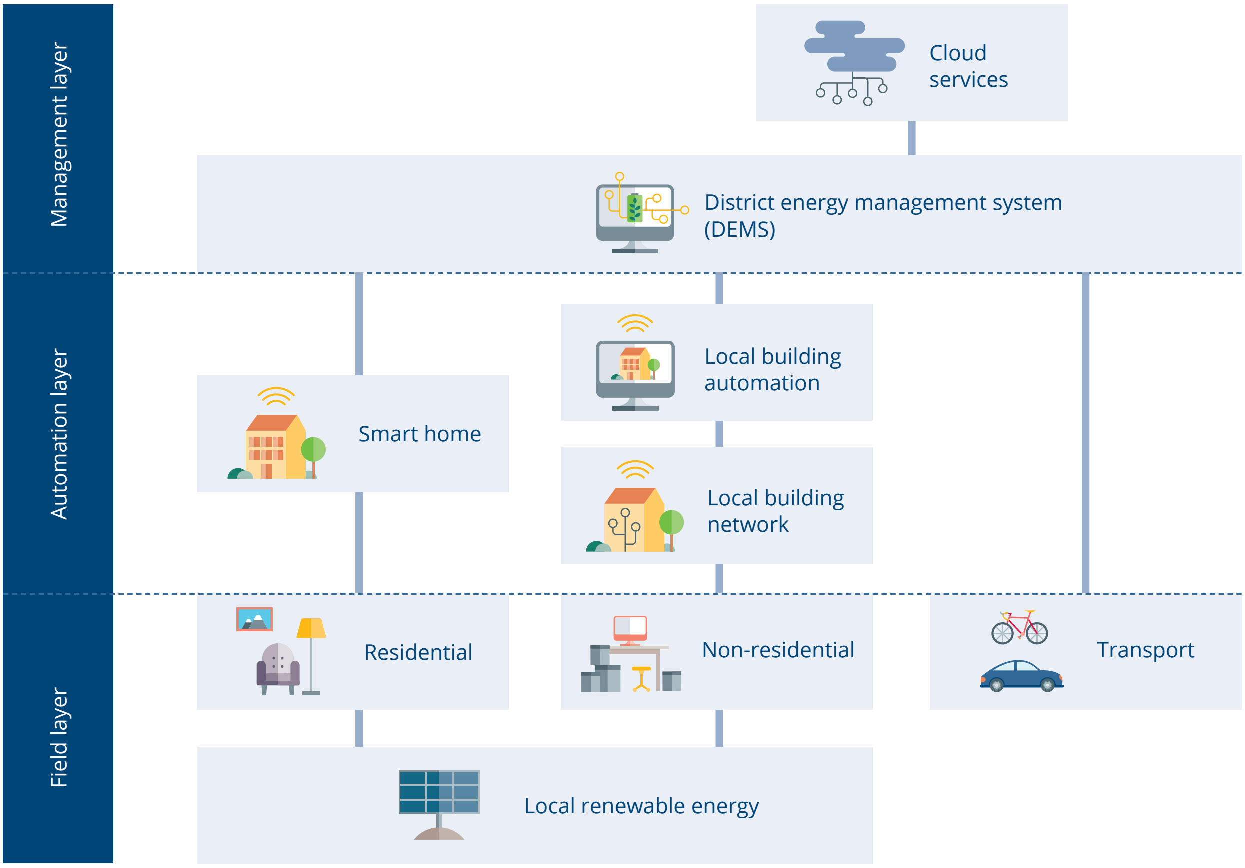

Figure 16: Basic structure and components of a District Energy Management System

the district together, aggregating and visualising them, and derives new control settings from this information (e.g. with Model Predictive Control (MPC) or Peak Load Contribution (PLC)). Connecting several buildings and additional parts of the energy system in the management layer allows the management layer to take over the visualisation and shifts control tasks from the automation to the management layer. An important question is where these processes, some of which are computationally intensive (MPC, agent-based control (ABC)), take place. In addition to local resources in the district, cloud services are a promising option. In practice, many different communication protocols exist in the field, automation and management layers. Future district control systems must be able to process these different protocols.

Takeaway:

It is essential to control the energy system in order to fully utilise the potential of technologies and avoid unnecessary energy losses. It is important to define the objectives of the control system and find an optimum between the different interests and motivations of stakeholders. The aggregator operating this system plays a crucial part in connecting the various roles and tasks across the different layers, sectors and stakeholders. The district developer must find a professional partner to fill this role over a longer period of time to succeed in setting up a district energy management system. Interfaces between the different stakeholders (see step 1) and their corresponding optimisation strategies need to be coordinated by the investor of the energy management operator to ensure all the involved stakeholders are committed to the project.

Showcase: Benjamin Franklin Village in Mannheim, Germany

A new district was constructed in the former US Benjamin Franklin Village in Mannheim after the area had been returned to the local authority. An integrated energy concept was established here, considering district heating and electricity demand for end consumers and e-mobility. Additionally, a buffer storage system for heat was installed.
All the installations are controlled by a platform that optimises the self-consumption of electricity based on the prices for selling and buying electricity as well as heat demand and the charge level of the heat storage systems. In times of low electricity sell prices, power-to-heat installations can transform the electricity surplus into heat. Furthermore, the installations also participate in the balancing power market, for instance, curtailing PV electricity production in times of high prices for negative balancing power or flexibilising charging operation of electric vehicles. Combined with local PV production forecasts, the heat grid and its economic efficiency are optimised.

An important precondition is that the municipal ESCO be responsible for both the heating grid and PV plant operation so that the optimised operation unleashes benefits in other areas, such as power-to-heat installations in the balancing market and the direct use of local PV production in the power-to-heat installation or e-mobility.

More information
(German)

6.2 Scenario planning: A model district

In the previous steps, the relevant tasks for setting up a district energy system are discussed on a theoretical level. To illustrate how this is applied in practice, these aspects are combined in a modelling example showcasing scenarios for a fictitious commercial district in Germany.

Simplifications and assumptions are made for modelling the energy demand, local energy sources and the overall system in addition to the economic and ecologic assessment in this study. Weather data is from the German Meteorological Service for the city of Aachen in 2015. The results do not represent explicit planning or a detailed simulation but are rather intended to illustrate the effects of different energy system scenarios. The district is hypothetical.

Definition of the district and system boundaries

A commercial district with different uses is provided as an example. The different buildings’ years of construction are grouped to specific thermal transmittance values using TEASER. The sizes and geographical boundaries are defined using the characterisations provided in step 2. For the assessment, the sectors and boundaries to be considered must be determined.

Energy sectors: The subsequent investigations consider the following energy sectors: electricity, heating and cooling. As a significant simplification, only energy uses in buildings are taken into account. This excludes public charging stations for e-mobility and other public energy demand from the investigation.

Energetic and ecological balancing: The "Geographic Plus" approach was chosen for the district's energy balance. Using the "Geographic Plus" approach (see step 2), everything within an administrative boundary and the easily traceable imported energy flows in that administrative part of the city are considered. In this investigation, the imported energy flows are electricity, natural gas and green hydrogen.

Characterisation of the use and infrastructure

- Heterogeneous use and strongly differing/individual user behaviour
- Offices and warehouses, including a few light industries with low-temperature process heat demand
- Different building standards (building ages) and strongly varying energy intensities due to use
- Availability of existing infrastructure (mostly gas, electricity)
- New infrastructure difficult to develop

KPIs for the district	
Number of buildings	100
Gross floor area	281,500 m^2
Floor space index	0.5
Building composition	
Industry	40%
Offices	30%
Retail facilities	29%
Hotels	1%
Year of construction	
Before 1977	44%
1977–1984	27%
1984–1995	18%
After 1995	11%

Table 13: District characteristics

The locally used electricity and heat are calculated as KPIs for the energy balance. Cooling is not explicitly considered as it is provided using electric energy (compression chillers or geothermal pumps) in all the presented scenarios. Furthermore, an hourly electrical residual load profile is calculated that, in addition to the annual KPIs, determines when energy must be imported.

As a further simplification, a full life cycle analysis is not performed as part of the study. In the following, only the operation and the energetic and ecological expenses associated with the direct operation are taken into consideration. The operational CO_2 emissions are used as a KPI for the ecological assessment. The imported energy flows are assigned constant CO_2 factors and included in the ecological assessment. Hydrogen is always considered to be green hydrogen without any CO_2 emissions.

Economic accounting: For economic accounting purposes, the investment's simplified net present value is determined over a certain observation period. The net present value (NPV) corresponds to the sum of all incoming and outgoing payments due to the investment made. This value is determined over a fixed observation period; all regular payments (e.g. energy costs and CO_2 costs) made after the investment are discounted (i.e. discounted to the present date). The net present value considers the lifetime of the investment; if the lifetime of the investment exceeds the observation period under consideration, this must also be discounted to the time of investment as the residual value.

In this concept study, some simplifying assumptions are made to determine the NPV:

- All necessary investments are made at time 0 (i.e. in the first year).
- The annual payments (e.g. energy costs) remain constant.
- No revenue comes from selling energy to customers. This assumption can be interpreted in such a way that the energy used (heating, cooling and electricity) has the same value and thus the same price in every scenario.
- Inflation and price increases are balanced out by the interest rate.
- The residual value (especially of the district heating pipes) depreciates on a linear basis, i.e. after half the lifetime, the investment has a residual value of 50%.

The costs for importing energy and the prices for exporting electricity are assumed constant.

- Linear functions are assumed for the investments depending on the installed power (see Table 18 and Table 19).
- The period under consideration is set to 15 years.
- The interest rate is set to 6%.

All prices, costs, and other assumptions are rough estimates that do not do adequate justice to the complexity of energy system planning with different business cases. The goal of the energy and economic modelling in this guidebook is not to cover an exact energy system planning with all uncertainties. Rather, it is to compare different systems under comparable conditions. The evaluation (both energetic and economic) may be different for similar districts with changed boundary conditions.

Characterisation of the energy demand

According to the defined size of the district (number and type of buildings) and the sectors to be considered, the hourly heating, cooling and electricity demand must be determined for all the buildings. A simplified building model is used in this project to simulate the thermal demands (heating and cooling demands) depending on the usage, size and age of the building. Detailed data are estimated based on a few input parameters (e.g. building use, building age, gross floor area). Hourly electricity demand is determined using German standard load profiles for different uses.

This calculation provides hourly demand values for all 100 buildings, which can now be analysed in more detail. A clear seasonal profile due to the heating demand in winter is visible, although a relevant part of the heat demand is requested by a process that needs heat all year round. The district has a significant cooling demand due to the high proportion of office buildings. Seasonal fluctuations in electricity demand are less pronounced in the commercial area. The high absolute and specific electricity demand and required power due to commercial processes are particularly significant. Figure 16 shows the hourly time series for heating, cooling and electricity demand.

Characterisation of the local energy sources

An ambitious strategy is pursued to use local energy sources to cover as much of the local energy demand as possible in the interest of minimising energy imports and reducing the risk of future price increases. Moreover, it is easier to trace the climate neutrality of local energy sources compared to energy imports (such as the electricity mix generated by different sources). For this purpose, all buildings are equipped with a PV system. To calculate the output of the PV systems, it is assumed that all roofs are flat and that 60% of their surface area is set aside for PV use. The capacity (i.e. area) is set beforehand and is not part of an optimisation. The reason for the relatively low roof utilisation rate for commercial buildings is that additional technical components are often located on the roofs (e.g. ventilation technology or elevator shafts). Another assumption is that the PV cells are ideally oriented to the south with a 30° pitch. The PV cells have a constant efficiency of 14% to the irradiation on the tilted surface. The resulting PV power generation profiles can be seen in Figure 18. The pattern is identical in all scenarios since the same weather data is used for

Demand Type	Value
Specific space heating demand	48.3 kWh/m²
Specific process heating demand	4.3 kWh/m²
Specific cooling demand	27.1 kWh/m²
Specific electricity demand	125.1 kWh/m²
Specific heating power	34.0 W/m²
Specific cooling power	32.7 W/m²
Specific electricity power	28.4 W/m²
Heating/cooling flow temperature	80 °C / 6 °C

Table 14: Characteristics of energy demand in the district

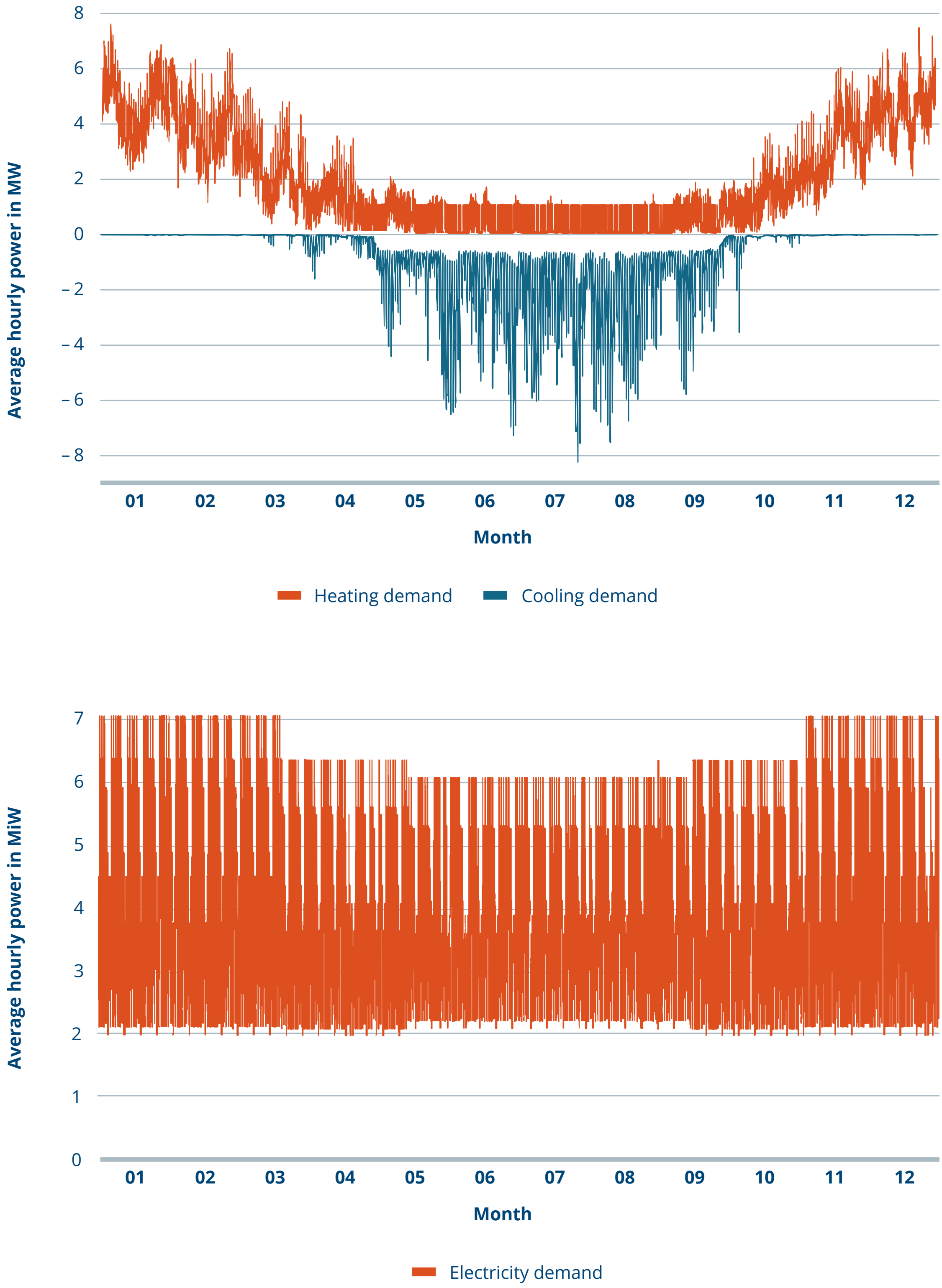

Figure 17: Hourly time series for heating, cooling and electricity demand over the year

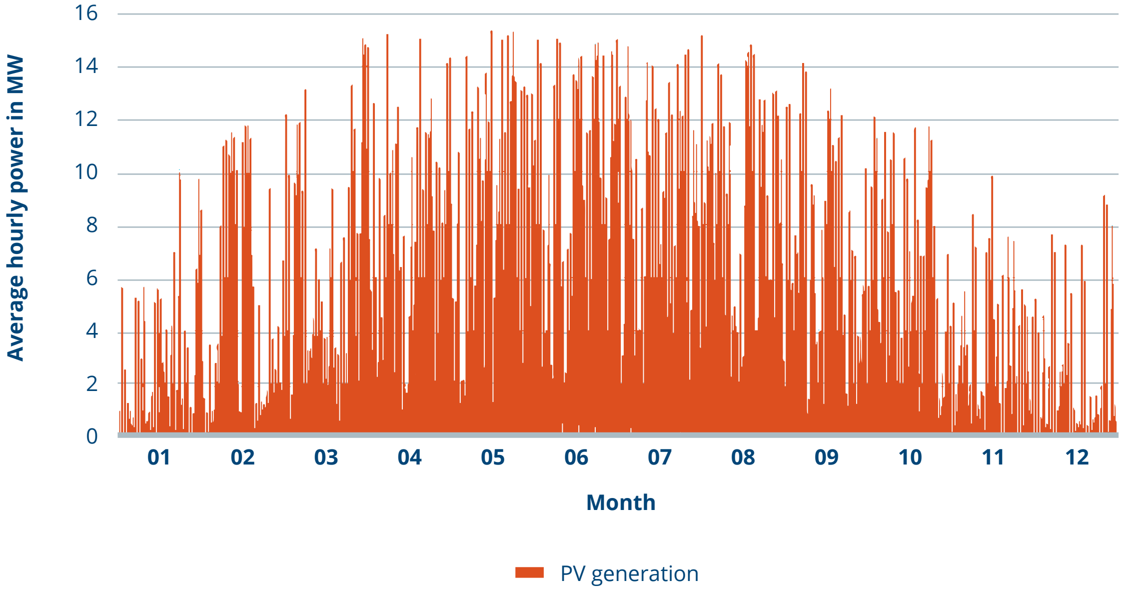

Figure 18: Total electricity production

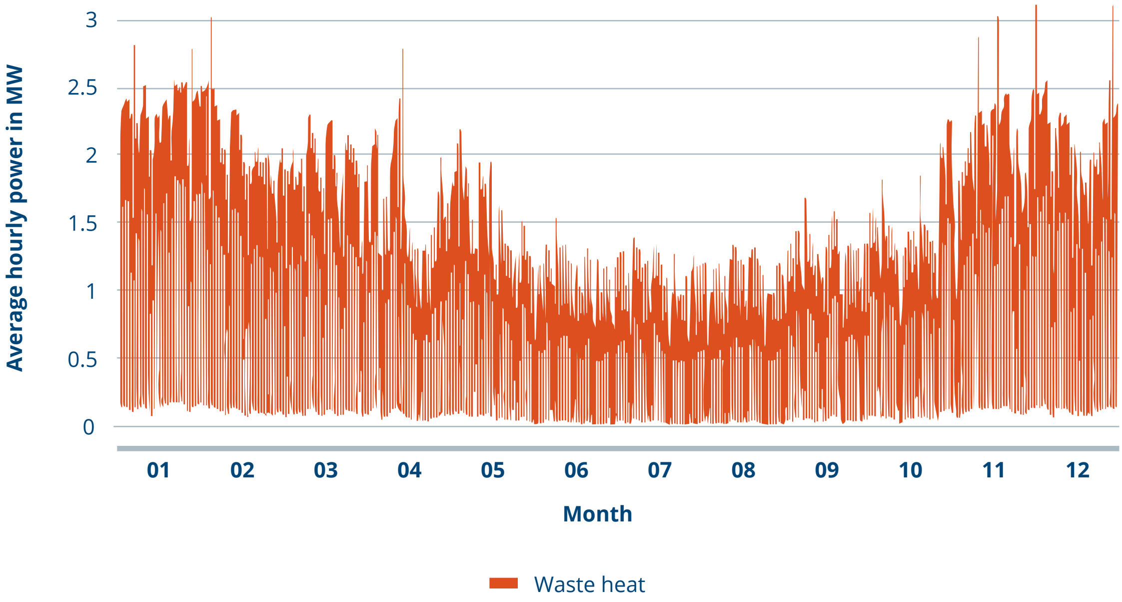

Figure 19: Waste heat potential

both calculations. In addition to the PV systems, renewable heat sources in the form of waste heat are also utilised. The waste heat potential in Figure 19 shows higher availability of waste heat in winter compared to summer.

Definition and simulation of the energy supply scenarios

A total of three different scenarios are calculated to compare the status quo with two scenarios relying mostly on electricity or hydrogen. A decentralised supply with gas boilers and chillers serves as the reference baseline scenario. In this baseline scenario, no renewable local energy sources are used (i.e. no PV and no geothermal/waste heat). The system's exact characteristics are specified as part of the presentation of the simulation results. An all-electric scenario and a hydrogen scenario are investigated for the district. In both scenarios, the PV systems are fully expanded, and a waste heat source is connected to a district heating network. A thermal storage system buffers the waste heat. In the all-electric scenario, a central high-temperature air-source heat pump is connected to the district heating network and provides the remaining heating demand. The all-electric scenario uses a central electricity storage system. In the hydrogen scenario, the CHP only uses green hydrogen and is heat driven; the electricity can be used locally. Excess PV electricity is stored using electrolysis and a hydrogen storage system.

Baseline scenario: Decentralised gas boilers

In the baseline scenario, decentralised boilers and compression chillers form the basis of the energy system. All the energy, i.e. electricity for household electricity and compression chillers as well as natural gas for the gas boilers, are imported into the district.

Figure 20 shows a simplified Sankey diagram of the energy system. Despite the magnitude of the three sectors, the general findings do not change for the district.

The baseline scenario already shows that OPEX costs are a key driver. For the baseline, OPEX exceeds CAPEX many times over. The reason for this is the high energy demand. Accordingly, the CO_2 emissions are also much higher. The structure of the investment costs shows that there is a stronger focus on cooling.

The baseline scenario can be summarised by simple conversion processes that cannot exploit synergies between sectors. No local energy sources are exploited, leading to the import of 100% of the electricity and natural gas. The continuous import of electricity results in a positive residual load profile at all hours all year long.

Energetic	CO_2 emissions	14,000 t/a
	Share of local electricity	0%
	Share of local heat	0%
Economic	NPV	-143,250,000 €/a
	CAPEX	-2,653,000 €
	OPEX	-13,140,000 €/a
	Cost composition	
	Chillers	54%
	Gas boilers	30%
	Design & startup	17%

Table 15: Key results in the baseline scenario

All-electric: Waste heat and central air source heat pump

In the all-electric scenario, waste heat and central air source heat pumps are the basis of the district's energy system. The heat is distributed in a thermal grid, and decentral chillers cover cooling demands. Two storage systems are implemented in this scenario: a thermal storage system (20 MWh ~ 450 m^3) buffers the waste heat, while a central electric storage system (20 MWh) stores residual load from the PV system. The PLC control first tries to use waste heat and the stored waste heat. The buffer storage is only charged if the heat demand is lower than the waste heat potential. If the waste heat is too low to satisfy the heat demand, the air source heat pump is activated. First, there is a verification to see if the PV electricity can be used for the heat pump or compression chiller, and then the commercial electricity demand is covered. If the PV system covers the entire electricity demand, an attempt is made to charge the storage unit. If

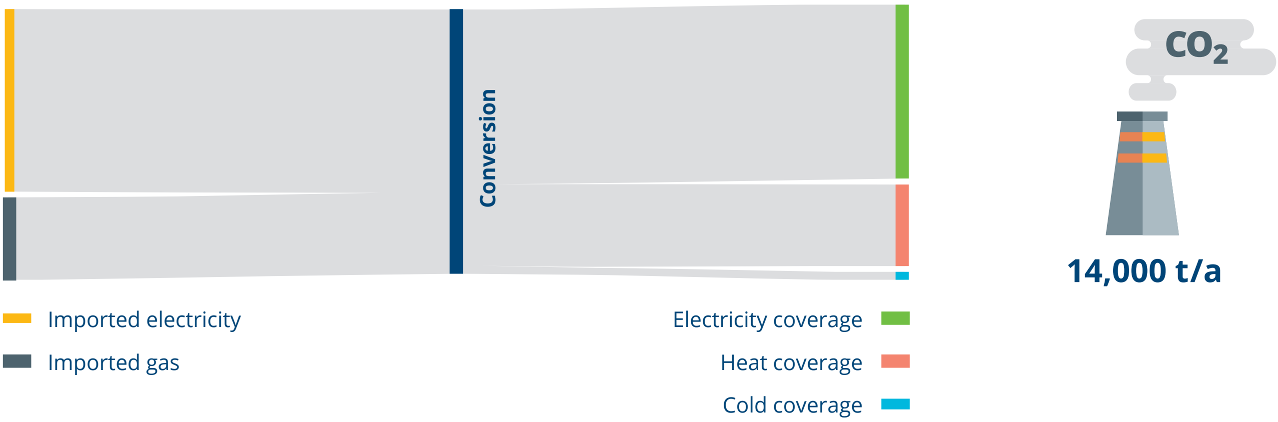

Figure 20: Sankey diagram and KPIs for CO_2 emissions and NPV for the baseline scenario

the storage unit is fully charged, the electricity is exported. If there is no PV power available, the storage is first discharged, and then power is imported.

Figure 21 shows the Sankey diagram of the all-electric scenario in the district. In comparison to the base scenario, less electricity is imported. Almost all locally generated electricity can be used; only a very small fraction is exported. This is due to the high energy demand of the district (electric demand + heat pump). Also, the waste heat can be used to a large extent directly in the district heating system. However, in the summer, large parts need to be cooled. Even with larger storage units for both electricity and heat, the district would always be dependent on the import of electricity for industrial use and to operate the heat pump. Local installations already cover 40% of the district's electricity demand and 43% of heat demand. Despite a significantly higher CAPEX, the NPV is higher (i.e. it is more economical) for the all-electric scenario compared to the baseline scenario, see Table 15 and Table 16. Similar to before, this is due to the low OPEX and the residual value of the heat grid. Compared to the baseline scenario, there is about a 50% reduction in CO_2 emissions. The remaining emissions are due to the high amount of imported electricity. Over time, it can be assumed that the share of electricity generated by renewable energies will increase as the central electricity supply is also undergoing a transformation process. This illustrates the interdependence between local and higher-level energy infrastructure levels.

The all-electric scenario shows that local electricity generation can always be consumed locally as there is a high demand all day and season long. Only a small amount of electricity is exported due to the relatively constant electricity demand. Using heat pumps results in higher electricity demands, especially in winter, leading to positive residual loads. As heat needs to be cooled in the summer, a seasonal storage system could be beneficial. Despite its high CAPEX, the NPV is higher than in the baseline scenario, resulting in a more economical operation compared to the baseline scenario.

Hydrogen: Waste heat and hydrogen combined heat and power

In the hydrogen scenario, heat is mainly generated by hydrogen-fuelled CHP. As before, the waste heat is used and distributed by a thermal network, and cooling demands are satisfied using decentral chillers. Two storage systems are implemented in this scenario: a thermal storage system (20 MWh ~ 450 m^3) buffers the waste heat, and a hydrogen storage system (20 MWh) is connected to an electrolyser. The electrolyser uses PV electricity exclusively. The control system first tries to use waste heat and discharges the waste heat buffer storage. The buffer storage is only charged if the heat demand is lower than the waste heat potential. If the waste heat is too low to satisfy the heat demand, the CHP is activated to produce heat and electricity. First, it uses the hydrogen from local storage; if the local hydrogen storage is empty, the CHP can use imported green hydrogen. For the electric control, the electricity produced by the PV and CHP systems is first used for the compression chillers and the industrial electricity demand. If the PV system covers the entire electricity demand, an attempt is first made to charge the storage unit using electrolysis (efficiency 65%). The storage can be discharged using the CHP. If the storage is fully charged, the electricity is exported. If there is no PV or CHP power available, energy is imported.

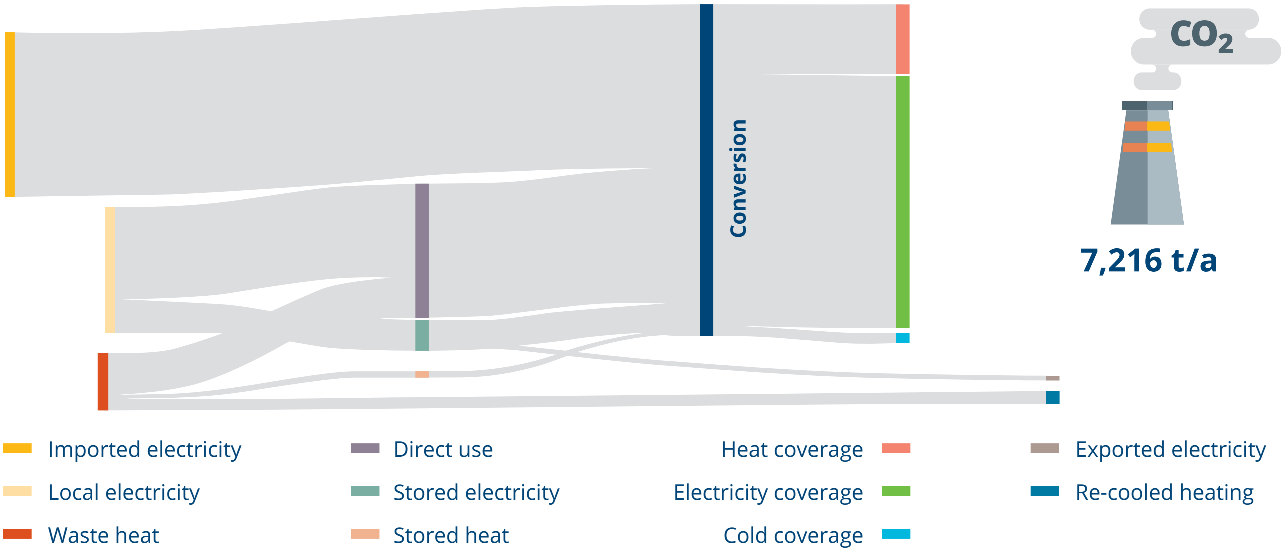

Figure 21: Sankey diagram and KPIs for CO_2 emissions and NPV for the all-electric scenario

Energetic	CO_2 emissions	7,216 t/a
	Share of local electricity	40%
	Share of local heat	43%
Economic	NPV	-114,425,000 €/a
	CAPEX	-42,630,000 €
	OPEX	-7,370,000 €/a
	Cost composition	
	PV systems	36%
	Electric storage	23%
	Design & startup	17%
	Heat pumps	10%
	Heat grid	7%
	Waste heat installations	3%
	Chillers	3%
	Thermal storage	≈0%

Table 16: Key results for the all-electric scenario

Figure 22 shows the Sankey diagram of the hydrogen energy system. Compared to the all-electric scenario, the primary energy demand for heating is higher. This is due to the lower efficiency of the hydrogen conversion in CHP (see Figure 12) compared to heat pumps. Moreover, because the CHP is operated in head lead mode (winter), the hydrogen is only imported for heat, as the electricity the CHP produces is considered local power production. In the summer, the CHP is only operated with hydrogen from local storage. Less electric energy is stored due to the electrolysis efficiency losses. A higher share of electricity – the excess power the CHP produces in the winter – is exported as this electricity is not reused for electrolysis.

A high share of locally generated electricity can be used directly or via storage systems. The electric power generated by the head lead CHP is considered local energy, leading to a negative residual load profile in winter. While this has economic and ecological drawbacks to the local district (expensive to import hydrogen, and hydrogen CHP is less efficient than heat pumps), it can benefit other districts (e.g. all-electric districts with a positive residual load in the winter. The CHP electricity increases the locally used electric power to 66%. However, the large hydrogen imports to operate the heat-led CHP decrease the locally used heat to 23%.

As shown in Table 17, the CAPEX in the hydrogen scenario is even higher than in the previous scenario. The main drivers of the high investments are the CHP plant and the electrolysis required for the storage system. In contrast to the all-electric scenario, the investments in the storage system itself are negligible compared to the other investments. However, the higher CAPEX is offset by a lower OPEX. Moreover, the total electricity demand decreases since there is no need to operate a heat pump. The CHP operation offers an economic advantage due to the heat-led operation and the locally used electricity. The NPV is higher than in the baseline scenario (i.e. the hydrogen scenario is also more cost-efficient).

The hydrogen scenario also shows that local electricity generation can always be consumed locally as there is a high demand at all hours of the day and in every season. The heat-led operation of CHP plants leads to negative residual loads in the winter, which can be beneficial if linked to PV in the region. The share of locally used electricity is the highest among all three scenarios due to the wide application of CHPs. Seasonal storage can be considered to avoid re-cooling waste heat in summer.

Scenario comparison

Table 16 and Table 17 summarise the main results of the scenario comparison. Both the all-electric and the hydrogen scenario reduce CO_2 emissions compared to the baseline scenario. The lowest CO_2 emissions are achieved with the hydrogen CHP configuration (75% reduction). Still, it needs to be considered that the green hydrogen needs to be produced with renewable energies and imported into the district. This requires significant hydrogen transportation, distribution and storage infrastructures. The all-electric scenario reduces CO_2 emissions by 49%, while the main driver for emissions remains the import of electricity.

The NPV of the hydrogen and all-electric scenarios are in the same range (deviation < 3%). The low OPEX and residual value of the district heating network that can be used after the observation period of 15 years contribute to this. Both scenarios have a better NPV than the baseline scenario, which means that, over the observation period, both scenarios are more efficient, economic wise. In general, the energy system for the commercial area has a high OPEX because of the high energy demand. This results in higher CAPEX costs, especially for energy-intensive districts. The higher upfront costs and lower operating costs lead to a demand for investment and possible green finance instruments. Various business cases can be derived from this opportunity to operate infrastructure.

The hydrogen scenario is the only energy system with a negative electrical residual load in the winter due to the head lead CHP operation. This can be beneficial for higher-level energy systems as PV generation in winter is generally lower. Despite the electricity and hydrogen imports, both all-electric scenarios have the potential to become CO_2 neutral. However, importing energy (electricity and hydrogen) in the winter poses a challenge for the higher-level energy system. The positive residual load in the summer is less critical because of the higher penetration of renewables (PV) in the summer.

Energetic	CO_2 emissions	3,580 t/a
	Share of local electricity	66%
	Share of local heat	24%
Economic	NPV	-111,750,000 €/a
	CAPEX	-51,760,000 €
	OPEX	-6,170,000 €/a
	Cost composition	
	PV systems	30%
	CHP	27%
	Design & startup	17%
	Electrolyser	14%
	Heat grid	5%
	Chillers	3%
	Waste heat installations	2%
	Hydrogen storage	1%
	Thermal storage	≈0%

Table 17: Key results for the hydrogen scenario

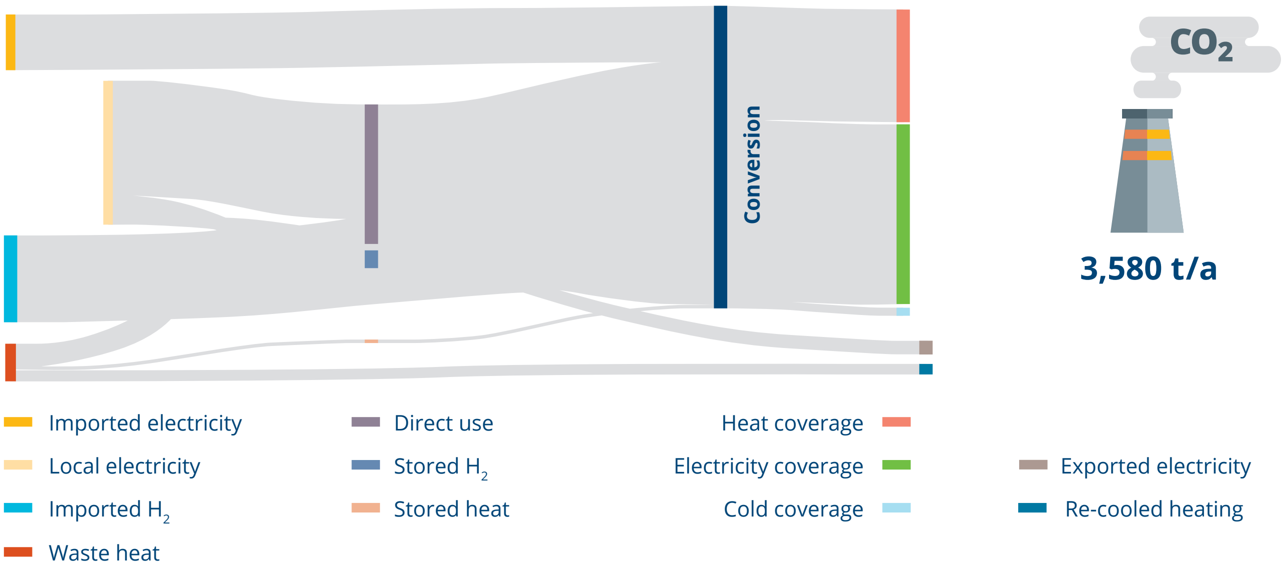

Figure 22: Sankey diagram and KPIs for CO_2 emissions and NPV for the hydrogen scenario

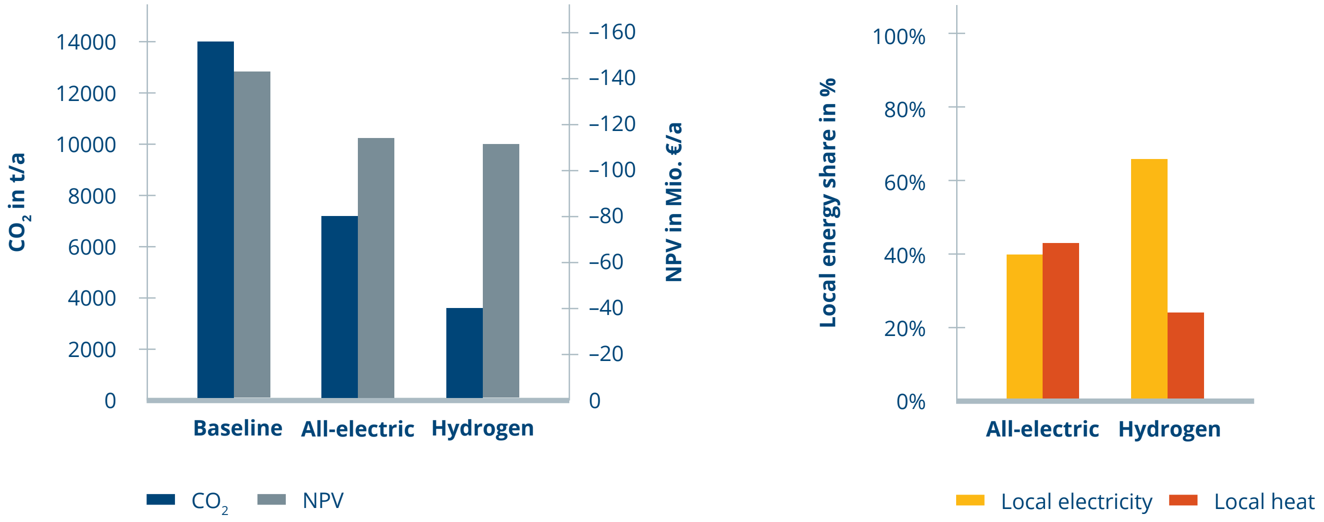

Figure 23: Comparison of KPIs for CO_2 emissions, NPV and locally used electricity and heat for all energy system configurations

Takeaway:

Both the all-electric and hydrogen scenario substantially reduce CO2 emissions and are more efficient in economic terms (considering the whole lifetime). Regarding the overall share of locally produced energy that is consumed locally, there is a difference between the 'all-electric' and 'hydrogen' scenarios. In the case of high-temperature process heat demand from certain industries, hydrogen might play a central role in the energy supply, which also affects the operation of the local heat grid as it cannot cover all temperature levels. Still, it must be noted that it is feasible to combine both scenarios, cumulating the advantages of both. Specific industries might cover parts of the hydrogen demand via local electrolysis from excess PV, while other temperature levels, such as for space heating, are covered using decentral heat pumps. Both scenarios have higher investments compared to the baseline scenario. However, costs can be saved in operation (especially by using local energy), making the net present value over the entire period for both scenarios better than the baseline.

Outlook

Once the outlined steps of initiation and planning are executed, the implementation and operation phases are crucial for achieving climate neutrality.

Project management needs to address the complexity of a larger number of stakeholders in the implementation phase. To date, there is no standardisation of climate-neutral implementation, and district developers rely on the expertise of the implementer on the construction site. Therefore, a professional implementer is key to avoiding delays or reduced quality due to the higher complexity of implementing climate-neutral districts. Here, professional suppliers and organisers must be included to avoid delays or reduced quality due to the more complex implementation. The approval authorities also need to be involved at an early stage as their flexibility is often needed. Sometimes, there are conflicting objectives for the protection of natural environments (flora and fauna), space, usage of the ground and the emission objective resulting from climate neutrality. Here, the different stakeholders need to find pragmatic solutions to optimise their different strategies and objectives. Moderation and solid communication are therefore key.

During the construction phase, traffic, waste, noise and emissions such as dust occur in the local environment, which can lead to resentment among neighbours as undesirable side effects of large-scale projects. In order to promote acceptance among the stakeholders affected by such negative impacts, these factors should also be taken into account during the planning phase and minimised as far as possible. Above all, in the context of climate-neutral construction, it is important to reduce material requirements and waste products and the associated emissions in this phase of the life cycle. In future considerations, the greenhouse gas emissions for production, construction, replacement, dismantling, disposal and, if necessary, maintenance can no longer be neglected. The entire life cycle must be considered from a holistic standpoint.

The operation phase is characterised by constant monitoring and optimisation of the district and, most importantly, its energy system. Unlike conventional energy systems, a more complex technical setup leads to the increased need for professional monitoring and subsequent optimisation of the installed energy system. The gap between planned and real-time values should not be underestimated, as the actual operation often leads to unforeseen consequences. This is especially the case if private end users in the residential sector are involved, as their behaviour is particularly difficult to anticipate. The strategy involves first defining the objectives (minimise emissions, maximise self-consumption, maximise balancing power revenues, etc.) and prioritising them if they lead to conflicting results. Second, the necessary data collection points and subsequent data analysis are needed to develop a solid monitoring concept.

Another general point to consider is the long planning horizon for districts by integrated planning for climate neutrality. Short horizons for the amortisation of investments often put private stakeholders under pressure to realise fast returns. This hinders climate-neutral action, as its advantages often materialise in the long term in the shape of avoided costs, emissions and higher flexibility in the use of the district. On the other hand, the transformation towards climate neutrality is marked by increasing ambition by public decision makers at every administrative level (municipal, regional, national) and structural change in energy markets. Possible price hikes for fossil fuels related to CO_2 pricing and the downgrading of investment portfolios by financial stakeholders are a constant risk. Moreover, climate neutrality is becoming more relevant for office tenants to ensure their company's climate neutrality targets. Therefore, future changes need to be incorporated today by anticipating higher prices for future fossil fuel imports and emissions.

The involvement of public institutions, especially municipal ones, should not be underestimated. Local authorities have longer planning horizons compared to private investors. Synergies between them and the district developer can help to provide security for long-term decisions and subsequent risk. In the case of installations with long lifetimes (heat grids), the local authority can help to give guidance and ensure long-term economical operation. Helpful tools include municipal energy and infrastructure plans, which need to be synchronised with plans in the district. The local authority can also play a valuable role as an anchor customer to provide the necessary heat demand for initiating a heat grid. Also, as national governments continuously adjust climates, regions and local authorities are following suit. Therefore, district developers can already begin incorporating climate neutrality today and establish joint planning with the local authority to achieve climate neutrality in the most effective and economical way. In this regard, integrated district planning is key to bringing together all the relevant stakeholders and aspects to unlock potentials on the pathway towards climate neutrality.

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Annexe

	OPEX [€/MWh]	CO_2 [t/MWh]
Imported gas	86[1]	0.2
Imported electricity	280	0.30[2]
Imported hydrogen	140[3]	0
Waste heat	0	0
Exported electricity	- 5	0
CO_2 costs	100	-

Table 18: OPEX and CO_2 emissions for imported energy[4]

Device	Spec. invest. [€/kW] / [€/kWh]	Spec. invest. [€/n]	O&M costs [1/a]	Lifetime [a]
Gas boiler	70	2500	160 €	20
Chiller	152	1765	2.5% of invest.	15
Waste heat HP	544	296,770	2.5% of invest.	20
PV system	1000	2000	15 €/kW	20
Thermal storage	450	–	1.0% of invest.	40
Electric storage (central)	500	–	2.0% of invest.	15
Heat grid	400	–	1.0% of invest.	50
Waste heat source	400	–	1.0% of invest.	50
Hydrogen CHP	1920	–	2.0% of invest.	15
Electrolysis	1100	–	2.75% of invest.	15
Hydrogen storage	15	–	4.0% of invest.	15

Table 19: Investment, operation and maintenance costs for different energy system components[5]

[1] Hennes, Oliver, Samir Jeddi, Reinhard Madlener, Hendrik Schmitz, Johannes Wagner, Stefanie Wolff, and Jonas Zinke. (2021, June). Auswirkungen von CO_2-Preisen auf den Gebäude-, Verkehrs- und Energiesektor.

[2] Fritsche, U., & Greß, H. (2020, November). Der nichterneuerbare kumulierte Energieverbrauch und THG-Emissionen des deutschen Strommix im Jahr 2019 sowie Ausblicke auf 2020 bis 2050.

[3] "WD 5 - 3000 - 029/20", 5.

[4] Data provided by dena

[5] Data provided by dena

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